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Estimating Aircraft Depot Maintenance Costs

Kenneth E. Marks, Ronald W. Hess

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Describes a series of parametric equations for use in estimating the depot maintenance cost of new Air Force aircraft, particularly for the five major maintenance categories: airframe rework, engine overhaul, airframe component repair, engine component and accessory repair, and avionics component repair. The equations are intended to provide cost estimates for Defense Systems Acquisitions Review Council Milestone II, at which point some design details of major aircraft subsystems (airframes, engine avionics) are available. The report presents a single set of equations that are the most representative and applicable to the widest range of estimating situations, but presents alternative equations and supporting data and analyses for use by the interested reader. (See also R-2552-PA&E.) (WH)

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Estimating Aircraft Depot Maintenance Costs

Kenneth E. Marks, Ronald W. Hess

July 1981

A report prepared for the
Office of the Assistant Secretary of Defense/
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PREFACE

This report presents the results of Rand research on parametric methods for estimating the annual depot maintenance cost of new Air Force aircraft. The research focused on methods suitable for use at or near Defense Systems Acquisition Review Council (DSARC) Milestone II--that is, prior to the initiation of Full Scale Development. These methods make use of information about the design and maintenance characteristics of new aircraft to provide estimates suitable for life cycle cost analysis and planning studies. The methods are not intended for detailed programming and budgeting of depot maintenance activities.

The work documented here was sponsored by the Office of the Assistant Secretary of Defense, Program Analysis and Evaluation (PA&E). The results should be of interest to cost analysts in both the OSD and the Air Force system acquisition and logistics communities.

A related cost often associated with depot-level aircraft maintenance requirements is that of recoverable spares investment. Recent results on this subject are published in K. J. Hoffmayer, F. W. Finnegan, Jr., and W. H. Rogers, Estimating USAF Aircraft Recoverable Spares Investment, R-2552-PA&E, The Rand Corporation, August 1980.

SUMMARY

This report describes a series of parametric equations for use in estimating the depot maintenance cost of new Air Force aircraft. The equations are intended to provide cost estimates for Defense Systems Acquisition Review Council Milestone II. At that point in time, some design details of major aircraft subsystems (airframe, engine, avionics) are available, but existing estimating equations reportedly do not make use of this information. This work specifically sought to include subsystem-level, as well as system-level, parameters in the equations developed.

Experienced logisticians at three Air Force depot maintenance facilities were consulted to identify factors that affect the depot maintenance cost incurred by aircraft weapon systems. Their views were combined with knowledge accumulated at Rand during previous studies to form the basis for selection of potential explanatory variables for use in the parametric estimating equations.

Data on the depot maintenance cost of most major USAF aircraft and aircraft engines for fiscal years 1975 through 1977 were obtained from the Air Force Logistics Command. The primary data source was the Weapon System Cost Retrieval System. Data were also obtained from the standard AFLC supply and maintenance cost reporting systems (D041 and H036B). The data were analyzed in conjunction with data on potential explanatory variables at both the system and subsystem levels. The analyses centered on the development of useful estimating relationships for the five major categories of depot maintenance: airframe rework, engine overhaul, airframe component repair, engine component and accessory repair, and avionics component repair.

Equations were developed that relate airframe rework cost to flying hours, aircraft empty weight, depot production quantity, programmed depot maintenance policy, airframe manufacturing cost, aircraft age, and the percent of work performed organically. Similar equations for the depot-level repair of airframe components incorporate

empty weight, airframe manufacturing cost, sortie rate, and a variable that denotes whether or not the aircraft engine has an afterburner.

Equations developed for maintenance work on whole engines and engine components and accessories make use of turbine inlet temperature, pressure, specific fuel consumption, engine weight, thrust, removal rate, selling price, and variables that distinguish the aircraft mission, single versus multiple engine applications, operation by active versus reserve/guard units, and organic versus contract maintenance.

Avionics component repair costs are estimated by equations based on the avionics suite weight, the number of suite black boxes, the number of suite functions, the mean time between suite demands, the suite procurement cost, sortie rate, and mission and all-weather capability designators.

Several estimating equations are potentially useful for each of the depot maintenance categories. A single set of equations is presented as being, in our judgment, the most representative and applicable to the widest range of estimating situations. The alternative equations and supporting data and analyses are presented in the report, however, for use by the interested reader.

Several issues that are beyond the scope of this study should be addressed in future research. Chief among these are the effects of recent changes in aircraft and engine design practices on depot maintenance costs. Our data did not, for example, permit an analysis of the implications of engine modularity (as in the F100 engine) or of the increased use of composite materials (as in the F-15 and F-16). Similarly, we were unable to examine the effect of aircraft age on the cost of airframe rework and engine overhaul. Also, a detailed analysis of the basic H036 data could evaluate some data that were not included in the WSCRS data files. For example, data identifying individual facilities could be very useful in studies of maintenance concepts, indirect costs, or the relationships between the composition (and cost) of the labor force and the nature of the work performed.

ACKNOWLEDGMENTS

This study could not have been conducted without the cooperation of a large number of Air Force Logistics Command personnel. Personnel in the Directorates of Maintenance, Materiel Management, and Plans and Programs at the Ogden, San Antonio, and Warner Robins Air Logistics Centers provided advice and insights that were important in the development of hypotheses. All of the cost data used were provided by the headquarters. Special thanks are due to Roger Steinlage, Robert Boulais (AFLC/ACMCC), and Captain John Wallace (formerly of AFLC/ACMCC) for supplying data from the Weapon System Cost Retrieval System and providing information on the system periodically during the study.

CONTENTS

TABLES

FIGURES

GLOSSARY

The values of all cost elements listed in this glossary are expressed in fiscal year 1978 dollars.

ACFFD	Aircraft first flight date
ACI	Analytical condition inspection
AFCCST	Annual airframe component repair cost per aircraft
AFMFGC	Airframe manufacturing cost; cumulative average cost of first 100 units, including manufacturing labor and materials (millions of FY 1978 dollars)
AFRWKC	Annual airframe rework cost per aircraft
AGE	Aircraft average age, as measured and reported by AF/PAXRB (years)
ALC	Air Logistics Center; any one of five Air Force owned and operated depot maintenance facilities
ANNCTR	Annual cost to repair per engine
ATBO	Average time between overhaul (hours)
ATE	Automatic test equipment
AVCST	Annual avionics repair cost per aircraft
AVGCOH	Average cost per overhaul
AVWT	Avionics suite weight (lbs)
AWXDV	All-weather capability dummy variable (no = 1; yes = 2)
BITE	Built-in test equipment
BLBOX	Number of black boxes in suite (#)
CER	Cost estimating relationship
CIE	Controlled interval inspection
CODMC	Contracted-out depot maintenance cost
DCLC	Direct civilian labor cost
DoD	Department of Defense
D041	The Recoverable Consumption Item Requirements Computation System
DMC	Depot maintenance cost

DMIF	Depot Maintenance Industrial Fund
DMLC	Direct military labor cost
DSARC	Defense Systems Acquisition Review Council
ENGACC	Annual engine component and accessory repair cost per engine
EW	Aircraft empty weight (lbs)
FH	Fleet flying hours; the number of flying hours accumulated during a year by aircraft of a particular MDS
FHRATE	Same as FH
FUNC	Number of electronics functions performed by aircraft avionics suite (#)
GAC	General and administrative cost
H036B	Depot Maintenance Industrial Fund (DMIF) Cost Accounting and Production Report (H036B)
INV	Inventory size, the number of possessed aircraft
LRU	Line replaceable unit
MAINTPCT	Organic maintenance percentage; the percentage of cost that is associated with organic maintenance rather than contractor maintenance
MAXLDF	Maximum load factor; the aircraft design load factor (g's)
MAXTH	Maximum thrust (lbs)
MD	Aircraft mission/design
MDS	Aircraft mission/design/series
MILTH	Military thrust (lbs)
MISSDES	Mission designator (1 = bomber/cargo; 2 = fighter/attack)
MISSDV	Mission dummy variable (1 = noncombat aircraft; 2 = combat aircraft)
MISTR	Management of items subject to repair
MTBD	Mean time between OFM demands (hours)
MTBO	Mean time between overhauls (in engine flying hours)
NENG	Number of installed engines per airframe
NRTS	Not reparable this station
NSN	National Stock Number
O&A	Over and above; i.e., work over and above the usual requirement

ODC	Other direct cost
ODMC	Other direct material cost
OFM	Organizational and field maintenance; the levels of maintenance below the depot level
OIC	Other indirect cost
OSCAR	Operating and Support Cost Analysis Report
PDM	Programmed Depot Maintenance (1 = no PDM; 2 = has PDM)
PQ	Production quantity
PRSTERM	Engine pressure term (psf)
REMRATE	Base-level engine removal rate (# per 1000 engine hours)
RSVPCT	Percentage of engine operating hours flown by Guard/ Reserve personnel
SE	Support equipment
SEE	Standard estimate of error
SELLPR	Engine selling price (unit 1000 in 1978 dollars)
SFC	Specific fuel consumption (lbs/hr/lb)
SINGDES	Single engine designator (multiple = 1; single = 2)
SORTENG	Annual engine sortie rate (sorties/year)
SORTRATE	Annual aircraft sortie rate (sorties/year)
SRU	Shop replaceable unit
SUITE 1	Procurement cost of avionics suite at unit 100 (1978 dollars)
SUITE 2	Sum of D041 item (NSN) procurement costs for all items in avionics suite
TCSTPAC	Total cost per aircraft; the annual cost per aircraft for total depot maintenance cost, including all categories of depot-level activity
TEMP	Turbine inlet temperature (degrees Rankine)
TFDES	Turbofan designator (1 = no; 2 = yes)
TOTCST	Total annual cost; the total annual cost per aircraft for a single cost category
TRC	Technical repair center

TYPMTC	Type maintenance designator (1 = organic; 2 = contractor)
USAF	United States Air Force
WPC	Work performance category
WSCRS	Weapon System Cost Retrieval System
WT	Engine dry weight (lbs)

I. INTRODUCTION AND OVERVIEW

The Department of Defense (DoD) uses a basic three-level system of equipment maintenance: organizational, intermediate, and depot. In the Air Force, organizational and intermediate maintenance units are located at aircraft operating bases. Depot-level maintenance is typically the most complex work and is performed at a limited number of permanent facilities that are operated by, or under contract to, the Air Force Logistics Command. The depot facilities support the organizational and field maintenance units through overhaul, repair, and modification of aircraft, engines, support equipment, and their components.

Depot-level maintenance accounts for a significant part of the support cost of military aircraft. Reliable, accurate estimates of depot maintenance cost (DMC) are needed during the acquisition of new aircraft if life cycle cost is to be a criterion in acquisition decisions. Methods of estimation currently in use reflect the amount of design data available at different points in time. Early in aircraft development, DMC typically must be estimated as a total cost based on system-level parameters such as aircraft weight and speed. When a new aircraft is almost ready to enter production, detailed bottom-up estimates for major elements of DMC can be developed based on detailed knowledge of the design. A problem arises during an intermediate period in aircraft development. There is a point at which some subsystem-level information is known, and this information could serve as the basis for an estimate of DMC, but no suitable estimating method is available to make use of this information. This point often occurs at or near the Defense Systems Acquisition Review Council (DSARC) Milestone II.

An appropriate estimating method would include separate cost estimates for each of the major categories of depot maintenance activity--airframe rework, engine overhaul, component repair--with sensitivity to parameters specifically related to the subsystems

involved. Airframe rework activity is primarily inspection and repair of airframe structural components to correct the effects of corrosion and structural fatigue. An estimating method useful during the middle of the aircraft development process would account for the influence of both system- and subsystem-level design features that affect the need for airframe rework. Similarly, the usefulness of a method for estimating engine overhaul costs is related in part to its sensitivity to features of the engine that affect the frequency and scope of overhauls. Separate estimating techniques for maintenance of various categories of aircraft components should likewise be sensitive to the specific parameters that affect the individual cost categories.

An acceptable alternative approach would use parameters that are related to the individual categories, but use them in a single equation that estimates total DMC. Although this approach would not provide visibility of the relative contributions of different types of activity, it could offer useful sensitivity to subsystem characteristics.

APPROACH AND PRINCIPAL RESULTS

We have developed parametric estimating equations that provide improved sensitivity at a point in time near DSARC II. Statistically derived equations were developed for airframe rework, engine overhaul, depot repair of three types of components (airframe, engine, and avionics) and for total DMC. (Data were collected for depot-level maintenance of support equipment, but the costs of this action are relatively small and were not addressed in the development of estimating equations.)

The data used in this study covered fiscal years 1975 through 1977 and included the major Air Force combat, support, and training aircraft systems active during that time span. The study capitalized on the special opportunity offered by a data retrieval system developed by the Cost Analysis Group in the Office of the DCS/Comptroller at Headquarters, Air Force Logistics Command. The Weapon System Cost Retrieval System (WSCRS) extracts data from standard Air Force data systems and integrates them into a single data file. A major advantage

of WSCRS over previous methods of integrating DMC data is the treatment given to the cost of maintenance for aircraft components. Earlier procedures usually allocated almost all component repair costs. Some even allocated costs associated with components used on only one mission/design/series (MDS) of aircraft. Whenever a component is identified by stock number in the raw data, WSCRS allocates its repair costs to the MDSs that use that component. Repair costs for a specific component used on only one MDS are thus assigned to that MDS. Repair costs not charged to specific components are aggregated by Federal Stock Class and allocated to all MDSs. Because of the reduced dependence on cost allocation, these data provide a more accurate data base than could be obtained earlier--accurate in that the cost associated with each weapon system is a more realistic measure of the maintenance resources needed to support the system. (The USAF data reporting system developed for the Visibility and Management of Support Costs program has adopted the essence of the WSCRS data processing procedure.)

A major limitation of the WSCRS data is that they do not include maintenance costs for components two or more levels below an end item. Costs for depot repair of items removed from an airframe or engine are included whether the items are removed at the depot itself or at base level. Whenever repair of these items involves removal of failed lower-level components (which are usually repaired at the depot), the costs associated with these lower-level parts are excluded from the WSCRS data. This excludes as much as 95 percent of depot-level component repair cost for a weapon system.

In order to include lower-indenture component costs, the WSCRS data were supplemented for this study with data taken directly from standard AFLC maintenance and supply data systems (H036B and D041). These additional data were used to identify maintenance costs charged to specific components and to identify the MDSs that use those components. The cost for each lower-indenture component was then allocated only to the MDSs that use it, as was done by WSCRS for the first-indenture items.

The explanatory variables used to derive estimating equations with the AFLC data were selected to represent the factors that we and experienced logisticians believed to have significant influence on depot maintenance costs.

Our analysis produced a number of potentially useful equations for each of the major categories of maintenance activity; all of these are shown and discussed in Sec. IV. The equations that we believe are the most representative and applicable to the widest range of estimating situations are displayed in Table 1. The explanatory variables in these equations had values in the data base that span these ranges:

Characteristic	Data Base Range
Airframe empty weight (lbs)	4067-320,085
Engine pressure term (psf)	3400-65,840
Engine dry weight (lbs)	367-7475
Avionics suite procurement cost ($)	220,000-10,410,000

Despite their probable range of applicability, the estimating equations of Table 1 are not universal; nor are they clearly superior--in a statistical sense--to several of the alternatives documented in Sec. IV. We believe it best to review the results of the study as a whole before selecting the preferred set of equations. Moreover, this report has been organized to retain the salient data and plots needed to make that selection or to develop cost estimates by analogy. For these purposes, the interested reader should refer both to Sec. IV and to Apps. C, D, and E.

In using the equations of Table 1, or any of the other equations developed during this study, it is important to keep in mind the limitations imposed by the nature of the data. The airframe rework equation produces much larger costs for aircraft with a PDM program (Programmed Depot Maintenance) than for those without PDMs. It should therefore be used with caution, since it does not address offsetting cost differences that may occur in other support costs, such as base-level maintenance. The accuracy of the equations for predictive

Table 1

REPRESENTATIVE SET OF COST ESTIMATING RELATIONSHIPS

Category	Equation	R^2	SEE	F	N
Airframe Rework	$AFRWKC = 183\ EW^{0.344}\ PDM^{3.22}$ (.018) (.000)	.84	.62	52	23
Engine Overhaul/ Repair	$AVGCOH = 0.598\ PRSTERM^{.793}\ WT^{.390}$ (.000) (.008)	.82	.43	32	17
	$ATBO = 957000\ PRSTERM^{-.601}\ MISSDES^{-1.23}$ (.007) (.011)	.51	.67	7	17
	$ANNCTR = 2.72 \times 10^{-8}\ PRSTERM^{1.49}\ WT^{1.24}$ (.026) (.028)	.61	1.77	10	16
Airframe Components	$AFCCST = 0.788\ EW^{0.967}$ (.000)	.78	.54	116	34
Engine Components/ Accessories	$ENGACC = 0.0265\ PRSTERM^{0.778}\ WT^{0.677}$ (.001) (.001)	.84	.52	34	16
Avionics Components	$AVCST = 0.00455\ SUITE2^{0.858}\ FHRATE^{0.650}$ (.000) (.012)	.86	.46	41	16

Notes: All cost variables are in 1978 dollars. Statistics in right-hand columns are coefficient of determination, standard error of estimate, F-statistic, and sample size. Numbers in () are significance levels for individual variables.

purposes will be greatest for systems that have characteristics within the ranges of the data base parameters. An examination of the lists of equations in Sec. IV shows a pattern of nigh standard errors. That is, there is some substantial amount of variance in the data that is not accounted for by these equations. Nevertheless, based on past experience with similar equations derived from similar data bases, we believe that these equations are accurate enough to be useful at or before the DSARC II milestone in new weapon system development.

It should be noted that our equations were derived from data for aircraft that may not adequately reflect the technical and design concepts that will characterize future aircraft. For example, the F-16 and A-10 were excluded from the analysis (and the F-15 included to only a limited extent), because there was little or no depot maintenance experience on them in 1975 through 1977. This is important because at least some of the new concepts are intended to reduce maintenance costs. These concepts include modular engines, increased use of built-in test equipment, and airframes designed to be supported without a rework program. To the extent that these concepts are successful, our equations may overestimate the depot maintenance costs of future aircraft.

OTHER RESULTS

Although the primary reason for conducting this study was to produce estimating relationships, the results have value in another respect as well. The study results as a whole (equations, data plots, and tabulated data) provide a new look at the nature of depot maintenance for aircraft. All of the equations that meet our screening criteria (discussed in Sec. III) are included in the later sections of this report so that interested readers can study them all. A large number of data plots are included to convey further information about the nature of the data base. Most of these are in App. E, but some are part of the discussion of analytical results presented in Sec. IV.

Presenting a large number of equations and supporting data is worthwhile in two respects. First, the information contained in the

equations can enhance understanding of the factors that affect depot maintenance cost. Thus, the estimator will have a richer context in which to judge the applicability of specific estimating equations. Secondly, we are offering the user alternatives for each cost category that may be better suited in a particular case than any single equation that we might have selected if we chose to document just one. This is important since, in general, the study did not produce one equation for each cost category that is clearly preferred over all others. The user should review all of the results before selecting the equation or equations to be used in a particular situation.

REPORT ORGANIZATION

Section II offers descriptions of the natures of the individual categories of depot maintenance work. Section III describes the data base, discusses the explanatory variables selected for quantitative analysis, and describes the statistical analysis methods. The estimating equations that met the selection criteria specified in Sec. III are presented in Sec. IV. Section V summarizes the main findings of the study and suggests some ways to improve upon these results in future research. Appendixes are included to provide information more detailed than that presented in the body of the report. Appendix A gives definitions of various terms and variables. Appendix B describes the data processing steps used to produce the data base used in the statistical analyses. Cost and explanatory variable data are tabulated in Apps. C and D, respectively. Plots of the data are collected in App. E. Appendix F describes some alternative ways of addressing airframe rework costs.

II. CATEGORIES OF DEPOT MAINTENANCE ACTIVITY

Depot maintenance is performed on four major categories of items associated with aircraft: airframes, engines, aircraft components, and support equipment. Support equipment maintenance costs were not analyzed during this study because they are very small relative to the other categories. Component repair may be divided into four subcategories on the basis of the types of components repaired. The four are airframe components, engine components and accessories, avionics components, and armament components. Table 2 shows, for a few typical systems, the relative magnitudes of the costs in the various categories.

Table 2

TYPICAL ANNUAL DEPOT MAINTENANCE COSTS PER AIRCRAFT
(Averages for 1975-77; FY 1978 dollars)

			Component Repair			
MDS	Aircraft Rework	Engine Overhaul and Repair	Airframe	Engine	Avionics	Armament
A-7D	13,090	81,944	5,035	24,783	19,749	0
B-52H	230,913	38,415	73,698	47,104	160,808	4,040
F-4D	45,482	17,958	16,175	18,060	31,755	0
F-106A	55,583	37,211	25,119	38,486	69,226	504
F-111F	2,775	101,830	29,998	57,230	117,030	0
T-37B	1,648	3,681	1,547	1,824	4,595	0

Although Rand has worked with various aspects of depot maintenance in the past, the current insights of Air Force personnel actively involved in depot maintenance activities were felt to be an important source of information. Experts at three Air Logistics Centers were consulted about their views of the parameters that affect each category

of depot maintenance. Their inputs were combined with expertise available within Rand to develop the knowledge that formed the basis for selection of the potential explanatory variables that were evaluated during the study. Those variables are described in the next section. The rest of this section summarizes our general understanding of the natures of the four major categories of activity at the time we were selecting variables for quantitative analysis. In some cases the statistical results are consistent with our expectations; in other cases they are not. These expectations are presented here and in Sec. III in order to describe a comprehensive view of depot maintenance activities. The most accurate view of depot maintenance is perhaps given by the combination of these expectations and the collection of quantitative results presented later in this report. When the quantitative results do not agree with the expectations, either the expectations may be faulty, because of incomplete knowledge about the factors that drive depot costs, or the data base may be unable to capture the effects that do exist.

AIRFRAME REWORK

When an aircraft needs maintenance that is beyond the capability of the organizations located at the Air Force's operating bases, the needed work is accomplished at a central maintenance depot--either an Air Logistics Center or a contractor facility. The term "airframe rework" is used to identify depot-level work associated with whole aircraft (rather than individual components), but excluding the engines.

Installation of aircraft modification kits is one type of work that is included in airframe rework. An aircraft may visit the depot for a modification alone, or modification work may be done along with maintenance work. A given modification may or may not significantly change the performance characteristics or other features of the aircraft. That which does is of a different nature than recurring maintenance of a fixed system and is not included in this study.

The nature of airframe rework changes from time to time. In recent years, PDM has been a major element of airframe rework for many aircraft. PDM consists of a package of depot-level maintenance tasks performed at specified calendar intervals. Other elements of airframe rework are the Analytical Condition Inspection (ACI) program and the Controlled Interval Extension (CIE) program. Some aircraft are exempt from force-wide scheduled depot maintenance. For these aircraft an ACI program may make up most or all of the airframe rework activity.

A PDM package typically includes a core requirement of depot-level tasks plus work that is over and above the core requirement (O&A tasks), and work that could be accomplished by organizational or intermediate maintenance organizations but which can be performed economically by the depot once the aircraft is torn down for the PDM (economy tasks). The O&A work is the same type of work as the core requirements, but is planned as an aggregate man-hour requirement rather than as specific tasks. This is a way of providing for an amount of work that is required but that can be predicted only in the aggregate, and not in detail. Economy tasks differ from core and O&A tasks in that they do not call for depot-level skills or equipment. The amount of field-level work done at depot facilities has changed from time to time, at least partly because of explicit policy changes.

Despite the uncertainties associated with O&A tasks and past and (likely) future changes in field-level work performed by depot activities, the bulk of the work in a PDM package is driven by defects in the basic airframe structure. These defects are caused mainly by corrosion and structural fatigue. Analyzing the sources of these conditions gives clues to basic parameters that influence the cost of airframe rework.

Corrosion is related to the age of an aircraft and the environment within which it is operated: The more time an aircraft spends in a humid environment, the greater the corrosion problem is likely to be.

Structural fatigue is related to the aircraft's mission--to how it is used. Thus, different types of aircraft that perform different missions might be expected to have different PDM requirements.

ENGINE OVERHAUL

Periodically during its life, a jet engine undergoes major depot overhaul to restore it to a "zero-time" status. "In this process, the engine is completely disassembled and the parts go off in various directions to be reworked, modified, or condemned and replaced by new parts. Then, as the 'engine nameplate' moves down the depot floor, similar parts come back together and are reassembled. By the time the 'nameplate' gets to the end of the line, the whole engine is reassembled and is considered to be a zero-time engine; that is, one capable of achieving the full maximum overhaul time allowed for that engine before its next trip to the depot. Most of the parts now making up the engine were probably not in the engine when it arrived."*

The maximum number of flying hours which may be consumed before an engine must be returned to the depot for overhaul, regardless of how well it is working, is termed the maximum time between overhaul (MTBO). Few engines actually reach the MTBO, however. Base-level inspections often reveal signs of degeneration that are beyond base-repair capability because of a lack of either personnel skills or appropriate support equipment. Depending on the degree of degradation and the time remaining until MTBO, the engine may be repaired or may undergo a complete overhaul. The average number of flying hours consumed before an engine undergoes overhaul is termed the average time between overhaul (ATBO).

The MTBO is initially determined based on contractor inputs and initial testing. As the ATBO experience improves, through enhanced base-level repair capability and component improvement modifications, the MTBO is usually increased. Increasing MTBO is

*J. R. Nelson, Life Cycle Analysis of Aircraft Turbine Engines, The Rand Corporation, R-2103, November 1977, p. 33.

an Air Force policy decision based on actual experience with ATBO. At some point, however, the MTBO is usually determined to be long enough and is not increased further. This upper limit on MTBO presumably represents a balance between the perceived risk of a higher probability of in-flight failure and corrosive damage to parts and the cost of more frequent, but less expensive, depot visits.

The reasons for an engine being returned to a depot facility for repair are considerably more diverse than the reasons for overhaul. They include such things as premature part failure (misestimation of part life), unknown source of performance degradation, lack of proper maintenance support equipment, aircraft accident, and foreign object damage. Thus, the causes of engine depot repair are not always directly related to either engine or application characteristics. In general, however, it is not unreasonable to suggest that the same characteristics which influence overhaul cost will also influence repair cost.

The two most direct causes of engine maintenance are thermal fatigue and cyclic fatigue. Thermal fatigue (e.g., warping and cracking of turbine vanes and blades) is caused by both operation at high temperature and changes in temperature. Cyclic fatigue (e.g., wearing of discs and bearings) is caused by changes in the rotational speed of the engine. Thus, the frequency and amount of time at maximum power as well as the total number of throttle excursions are felt to have a significant impact on engine part life.

Other factors that may affect engine depot maintenance cost include the level of technology embodied in an engine's design, the number and size of engine parts and assemblies, and maintenance concepts and policies.

COMPONENT REPAIR

The depot repair of aircraft components is managed by the MISTR (Management of Items Subject To Repair) system. Items are submitted to

MISTR from the operating bases and from the depot. When a component fails during operations, the base-level maintenance force removes the failed item and substitutes a working item from stock. Certain items can be repaired only at the depot and are shipped there directly. Other items are coded for base-level repair but because of a lack of spare parts, maintenance skills, test equipment or the like, are sometimes shipped to the depot (coded Not Repairable This Station--NRTS--with an appropriate indicator of the reason why repair cannot be accomplished). The depot airframe rework and engine overhaul processes also submit components to the MISTR system.

The total population of components repaired at the depot includes airframe, engine, avionics, and armament items and assemblies. Each ALC is designated as a Technical Repair Center (TRC) for specific types of components. For example, the majority of avionics components are sent to Warner Robins ALC while landing gears are repaired at Ogden ALC. Therefore, like components will normally be funneled to the same depot.

Other things being equal, the depot maintenance cost of individual components of all types should increase with item demand rate. The maintenance cost for a collection of components should therefore be related to a total demand rate. In addition, the types of materials used and the complexity of the manufacturing tasks involved in producing components, as reflected in component procurement cost, may also be related to the amount and cost of material and labor needed to perform depot maintenance.

Since most items are processed through a component repair line in batches, the cost of repair should also be affected by considerations that determine whether or not the most economical lot size is used. Shortages, for example, may lead to repair in lot sizes smaller than the most economical.

Airframe and Engine

Many of the factors that influence the repair cost of airframe and engine components and engine accessories are the same as those that influence the cost of airframe rework and engine overhaul.

Avionics

The avionics subsystem is defined to include those components providing aircraft display, communication, navigation, fire control, countermeasure, and reconnaissance functions. The depot-level repair cost of these components depends on the frequency with which they are returned to the depot for repair and the extent of the required repairs. Factors that are believed to have a strong influence on the frequency and cost of avionics repair include the complexity and performance of the components, the environment in which they must operate, and the diagnosis and repair concept.

Armament

Aircraft armament consists of guns, bomb racks, missile launchers, and other components related to weapon delivery. The total repair cost of armament components for a weapon system is expected to increase with the system's number of guns, number of munitions stores hard points, total munitions load, and number of types of munitions carried. Each of these parameters reflects a different aspect of the amount of armament hardware on the aircraft. Some combination of them should be related to the overall scope of the maintenance effort needed for these components. The amount of work done at the depot level is extremely small--small enough that it is insignificant compared with other cost categories. Appendix C shows the data for the few aircraft that had armament costs at the depot during FY 75-77. Because those costs were so small, we did not analyze armament or develop estimating methods for it.

SUPPORT EQUIPMENT MAINTENANCE

As with armament, we did not prepare estimating relationships for support equipment (SE) costs; we collected some SE information during the early research stages of the study, however, and summarize it here for completeness.

Direct depot-level maintenance costs for SE are associated only with SE used at aircraft operating bases. SE used in depot-level maintenance of aircraft is maintained by the shops that use the equipment or by a Precision Measuring Equipment Laboratory supporting these shops. The associated cost is an indirect cost of the operation of aircraft maintenance shops. Base-level SE is similarly maintained by the using base maintenance organization to the extent possible, but SE that requires repair work beyond the capability of the base is either sent to an Air Logistics Center or to a contractor. This results in a depot maintenance cost within the scope of this study.

SE includes training aids and devices and maintenance equipment. Some maintenance equipment can be further identified as automatic test equipment (ATE). ATE is more complex (and likely to be more expensive to repair) than other maintenance equipment. The SE repair cost per aircraft can be considered to be the sum of three terms:

(1) The annual cost for repair of training aids and devices,
(2) The annual cost for repair of ATE, and
(3) The annual cost for repair of maintenance equipment other than ATE.

Each term includes the cost of overhaul of SE end items and repairs of SE components. SE costs were not analyzed in this study; they remain an appropriate area of investigation for future research.

SE depot maintenance costs probably vary by mission. In particular, combat aircraft are likely to have a greater cost than noncombat aircraft, because they are likely to have more sophisticated equipment on board and to be supported by more sophisticated ground equipment.

SE depot maintenance cost may increase with increases in aircraft fleet size and flying activity, as measured in flying hours or sorties. The number of SE maintenance tasks that are performed is likely to be driven by the usage of SE, which is influenced by both number of aircraft and the level of flying activity.

Maintenance equipment maintenance costs should be greater for new aircraft than for old aircraft, because electronics and automation are used more extensively with newer aircraft.

Maintenance equipment depot maintenance costs are expected to increase with increases in the per aircraft procurement cost, weight, and power consumption of an aircraft's avionics. Procurement cost, weight, and power are indirect measures of the amount of avionics on the aircraft.

Maintenance equipment depot maintenance cost should decrease with the use of built-in test equipment (BITE) in onboard avionics systems. The extent of the use of BITE can be measured by the fraction of avionics systems for which BITE is used.

The depot maintenance cost of maintenance equipment other than ATE should increase with the size of the aircraft supported, with size measured by aircraft empty weight or basic operating weight. Aircraft size drives the size and procurement cost of various types of work stands and ground handling equipment; and larger, more expensive equipment should be more expensive to maintain.

COMMON CONSIDERATIONS AFFECTING DEPOT MAINTENANCE

One important issue affects all categories of depot maintenance: The costs charged for a given depot-level task may depend upon where the task is accomplished. This effect can be felt in one of three ways.

First, the direct cost to perform a stated task may differ between ALCs, because their direct labor rates differ. An ALC charges for direct labor at a rate derived from the average pay of the direct labor personnel in the production division perfor ing the work. Each ALC will therefore have its own direct labor rate, reflecting the skill levels and experience of its workers and the general level of wages in its geographic area.

Second, hourly charges for indirect and overhead costs can also vary between ALCs, which may result in different total costs even when direct costs are equal. These differences would be due

to differences in the staffing of indirect and overhead functions and to differences in the allocation of these costs between the ALCs and other organizations on the same bases.

Third, total costs for similar work will differ between an ALC and a contractor, and between contractors. Contractors can change the sizes of their work forces and the mixes of skills within them more quickly than can the ALCs. This allows contractors to more readily match their personnel to changes in the types or amounts of work that come to them. PDM costs, for example, may vary between locations because of differences in aircraft condition. F-4s operating in the Far East (and reworked there) are likely to have a greater corrosion problem than F-4s operating in the southwestern United States (reworked in this country). This could drive the man-hours needed to perform a PDM. It could also affect the types of workers that contractors would hire to perform the PDM, resulting in differences in labor costs per man-hour. Contractor charges should therefore be more closely matched to the nature and scope of the work. As a result, two contractors with different total workloads are likely to have different costs for parts of their work that are similar. A contractor and an ALC are likely to have different costs for similar work because their total workloads are dissimilar and because the labor forces available for these similar tasks will not be alike.

These common considerations may have important influence on the magnitude of depot maintenance costs, but data limitations prevented their analysis during this study. These considerations should be kept in mind during any application of the study results.

III. DATA BASE AND ANALYTICAL APPROACH

This section describes general aspects of the quantitative analysis that produced estimating relationships presented in Sec. IV: the cost data base, the candidate explanatory variables, and elements of the analytic approach that are common to all maintenance categories. The scope of the cost data base is described, along with brief descriptions of the cost data sources. Appendixes A, B, and C present the cost element definitions, data processing steps, and tables of the cost data. The discussion in Sec. II of the nature of depot maintenance led to consideration of specific potential explanatory variables. These variables are discussed here, and sources of data for them are identified. These variables are defined in App. A; tabulated data are included in App. D.

COST DATA

Data for three fiscal years (1975, 1976, and 1977) were collected and analyzed for most of the aircraft and engines currently in the Air Force inventory. These were the only years for which WSCRS data were available. Data were organized in the working data base by category of depot activity:

- Airframe Rework
- Engine Overhaul
- Component Repair
  - Airframe Component Repair
  - Engine Accessory and Component Repair
  - Avionics Component Repair

Armament component repair costs exist in the raw data for only a few weapon systems. Where they do appear, they are very small. Consequently, they are not included in the working data base or the analytical work.

The total maintenance cost of interest for each category includes the costs for maintenance proper and for installation of Class IV modifications, where these costs are identified in Air Force data by Work Performance Category (WPC). Relevant WPC definitions are given in App. A. Class IV modifications are changes to the physical makeup of an aircraft that do not alter the mission, performance, or capability of the aircraft. Such modifications can be expected as a routine part of the support of new weapon systems, so their cost is included. The cost of modifications that do change the mission, performance, or capability of an aircraft are specifically excluded because they are outside the scope of normal system acquisition decisions.

The data collected by the Air Force for engine maintenance show no costs for Class IV modifications, so the data base for this study necessarily includes only costs labeled as being for maintenance work per se.

It should be noted that some raw records for 1977 do not contain a WPC code. This meant that there was no way to determine whether or not the costs in these records were associated with maintenance activities relevant to this study. With no better information than this, it was decided not to include these costs in this analysis. If it were known that all of the costs in such records for airframe work were relevant, the airframe rework costs of, for example, the A-7D, B-52G, C-5A, and C-130E, would be between one and six percent higher than the values used in this study.

Total cost is composed of seven individual cost elements:

- Direct Civilian Labor Cost (DCLC)
- Direct Military Labor Cost (DMLC)
- Other Direct Material Cost (ODMC)
- Other Direct Cost (ODC)
- General and Administrative Cost (GAC)
- Other Indirect Cost (OIC)
- Contracted-Out Depot Maintenance Cost (CODMC)

These are defined in App. A.

Excluded are the following costs that, for other purposes, might be considered elements of depot maintenance cost:

- o Cost of components and assemblies submitted to the MISTR line (Management of Items Subject to Repair) during overhaul or repair.* This cost is sometimes referred to as Direct Replacement cost of condemned reparables (which is considered a supply function).
- o Depreciation of capital equipment.
- o Material Cost at Standard Cost to Repair.
- o Other Work Performance Categories such as conversion, activation, inactivation, reclamation, and storage.
- o Transportation to and from the depot.
- o Pipeline components.

Three sources of information were used in the development of the cost data included in the working data base. The primary source of cost data was WSCRS. All of the cost information for airframe rework and engine overhaul/repair was taken from WSCRS. WSCRS also provided some component repair costs, specifically, costs of repairing line replaceable units (LRUs) and costs reported against a class of components rather than a specific component. The term LRU denotes a component that is removed from an aircraft or engine as a single unit. An LRU may contain removable elements that are termed shop replaceable units (SRUs). SRU costs were obtained from the Depot Maintenance Industrial Fund (DMIF) Cost Accounting and Production Report (H036B). In order to link SRUs with the appropriate aircraft, application data were obtained from the Recoverable Consumption Item Requirements Computation System (D041).

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*These MISTR-related test and repair costs are considered in the component rework section of this depot cost model.

All costs were converted to fiscal year 1978 dollars, using the indices given below, and averaged over the three-year period:

Cost Element	1975	1976	1977
DCLC	1.265	1.174	1.076
DMLC	1.187	1.128	1.067
ODMC	1.220	1.135	1.068
ODC	1.246	1.159	1.071
GAC	1.246	1.159	1.071
OIC	1.265	1.174	1.076
CODMC	1.246	1.159	1.071

Average costs were computed for the three-year period to minimize the problems associated with random year-to-year fluctuations in the magnitude of the maintenance work for any given system or category of activity.

EXPLANATORY VARIABLE DATA

The material presented in Sec. II was the basis for development of sets of explanatory variables for the various categories of maintenance activity. The variables and the sources of relevant data are shown in Tables 3 through 5. Appendix A contains definitions of all variables. The data are tabulated in App. D. Before a variable was accepted for use in this study, it had to satisfy three criteria:

- o Be logically related to cost (i.e., the variable must be felt to have a logical impact on the frequency or magnitude of cost)
- o Be readily available at DSARC II
- o Possess historical record

The first point was satisfied through the development of the background material presented in Sec. II. The information contained therein

about factors related to cost points to potentially useful variables. Our goal was to develop at least one quantitative variable for each factor--one variable which meets the other two criteria. Data availability at DSARC II is required because that is the point at which the equations are expected to receive the most use. A historical record was obviously a necessity if data were to be collected to support a quantitative analysis.

Airframe Rework

The main approach to airframe rework estimates the annual cost per aircraft. If a cost analyst can estimate a cost per aircraft, then he needs to know only the inventory size to get the total cost for a weapon system. Alternative approaches, considered in App. F, are to estimate (1) the average annual total cost for a fleet of aircraft, and (2) the product of average cost per rework and average number of reworks per year.

Because the aircraft in the data base vary greatly in age, we considered the possibility of basing the prediction of airframe rework costs on a model that would capture the various effects on cost that change over the life of a weapon system. This proved not to be feasible, because the time-histories needed to understand and quantify these effects are not available in any readily accessible form. Corrosion, for example, is thought by some experts to cause significant costs at periodic intervals. A fleet of aircraft that receives extensive corrosion repair will not need such work again for some time, until the effects that cause corrosion to occur have had some time to work. Then, when repair is necessary, it will probably be needed for all aircraft in the fleet at roughly the same time; and the cycle repeats. Quantifying such effects would require consistent data over several years. Such data are not readily available for any sizable number of MDSs.

Although no sophisticated representation of age is possible, age is included in the list of explanatory variables dealt with in the

Table 3

POTENTIAL EXPLANATORY VARIABLES FOR AIRFRAME REWORK

Variable	Source
SIZE	
Empty weight	SAC Charts#1
Maximum takeoff weight	SAC Charts
TECHNICAL/PERFORMANCE	
Maximum speed	SAC Charts
Typical speed	SAC Charts
Typical altitude	SAC Charts
Dynamic pressure at maximum speed	Computed#2
Dynamic pressure at typical speed and altitude	Computed
Maximum load factor	SAC Charts
Airframe manufacturing cost	Rand Data#3
Afterburner designator	SAC Charts
Fighter/attack designator	Assigned
Bomber/cargo designator	Assigned
Trainer designator	Assigned
UTILIZATION	
Fleet flying hours	WSCRS
Inventory	WSCRS
Age	Hq USAF/PAXRB
Sorties	Hq USAF/PAXRB
Percent of fleet operated by reserves	Air Force Planning Data
Percent of fleet operating in humid climate	See Note#4
POLICY	
Organic maintenance percent	Computed from Cost Data
PDM policy	T.O. 00-25-4#5
Production quantity	WSCRS

Notes:

#1 USAF Standard Aircraft/Missile Characteristics, Air Force Guide Number Two, various dates.

#2 Computed from appropriate speed and atmospheric density.

#3 Rand data collected for previous research on airframe development and production costs.

#4 Derived from aircraft operating locations specified in Air Force planning documents and standard climate categories.

#5 Depot Maintenance of Aerospace Vehicles and Training Equipment, Air Force Technical Order TO 00-25-4, various dates.

analysis. This allowed for the possibility of long-term effects that might be significant at a gross level even though they could not be modeled as detailed processes.

Corrosion is related to the age of an aircraft and the environment within which it is operated: The more time an aircraft spends in a humid environment, the greater the corrosion problem is likely to be. An older aircraft is therefore likely to incur more cost associated with corrosion treatment than a newer aircraft.

Structural fatigue is related to the aircraft's mission--to how it is used. Thus, different types of aircraft that perform different missions might be expected to have different PDM requirements. At a gross level one can distinguish three major mission categories: bomber and cargo, fighter, and trainer aircraft. Bombers and cargo aircraft tend to carry heavy loads while flying straight and level for long periods of time. Fighters carry relatively light loads for shorter periods of time, but must endure the stresses of combat maneuvering. Trainers fly short sorties with many landings and are flown by inexperienced pilots. (Similarly, some logisticians believe that pilots in the Air Force Reserve and the Air National Guard may impose different stresses on an aircraft than active pilots who may fly that specific aircraft type more often.)

Within a given type, different usage may be associated with differences in size, flight conditions, and levels of activity.

Airframe weight and aircraft empty weight are measures of the size of the aircraft. Airframe weight is the more direct measure of the amount of structural material in the aircraft; but data on empty weight are more easily obtained, and empty weight is highly correlated with airframe weight. Maximum takeoff weight is a measure of the total mass of the vehicle, including fuel and payload.

The altitude and speed that a specific aircraft uses on a typical mission may result in stresses of a different magnitude from those encountered by a similar aircraft under different flight conditions. Maximum altitude and maximum speed relate to the greatest magnitude of stress to be expected. Important features of fighter design are the

maximum load factor for which the vehicle is designed and whether or not an afterburner is used.

Also, for any aircraft, the number of landings per unit time is likely to be related to rework requirements for landing gear and related structural elements. Similarly, the numbers of flying hours and sorties per unit time are measures of the amount of use an aircraft receives.

For any type of aircraft, two aspects of the airframe design are relevant. The type of material used should affect the cost of material used during rework and the number of man-hours needed to perform the work. Also, it is possible that different design practices result in structures with different degrees of resistance to corrosion or fatigue. It is probably not possible to specifically identify these practices; but it contractors are consistent in their choice of design approaches, it may be that all aircraft designed by any one company have somewhat similar rework requirements.

In addition to aircraft characteristics, maintenance policies significantly affect costs incurred for airframe rework. A major policy is whether or not to have PDMs. A number of USAF aircraft, including the newest (the F-15 and F-16) do not have PDMs. They visit a depot only for modification, for an ACI, or because of unusual damage beyond the capability of field maintenance units.

The interval between PDMs on a specific airframe is, along with the scope of the PDM package, a major determinant of weapon system airframe rework cost. The maximum interval for a new aircraft is decided upon on the basis of the best available engineering information. The recommendations of the contractor building the aircraft receive considerable weight. The value of this initial interval is likely to be related to the same things that influence the scope of the PDM package, as described above. Typically, as experience with a weapon system increases, the maximum interval is extended. The maximum value permitted at any point in the aircraft's operating life is therefore a function of the initial value and the system's age.

An aircraft that undergoes a PDM can be reworked by a crew of workers dedicated to a particular airframe in a given PDM dock or by

workers dispatched from pools of specialists. Warner Robins ALC uses dock crews; San Antonio ALC uses specialist pools. F-4 aircraft are reworked at five facilities--Ogden ALC and four contractor facilities. Depending upon which site it visits, a particular F-4 may be reworked either by a dock crew or by specialists. This distinction could affect both the man-hours needed for a PDM and the average cost of a man-hour.

Engine Overhaul and Repair

The two primary components in determining engine lifetime overhaul cost are the average time between overhaul (ATBO), which reflects frequency, and the cost per overhaul, which reflects the scope of the overhaul work. Discussions with ALC personnel suggest that these factors vary with engine age in the manner illustrated in Fig. 1.

Based on this view of engine maintenance, a parametric model for an engine lifetime overhaul cost might then take the following form:

(i) $\text{ATBO}(i) = f(\text{TECH}, \text{APPLIC}, \text{AGE}(i))$

(ii) $\text{OHAGE}(j) = f(\text{FLYPRG}, \text{ATBOPRG})$

(iii) $\text{NLOH} = f(\text{FLYPRG}, \text{ATBOPRG})$

(iv) $\text{COH}(j) = f(\text{TECH}, \text{APPLIC}, \text{OHAGE}(j))$

(v) $$\text{LIFOHC} = \sum_{j=1}^{\text{NLOH}} \text{COH}(j)$$

where

AGE(i) = engine age in year i
APPLIC = engine application characteristics (aircraft characteristics)
ATBO(i) = ATBO in year i
ATBOPRG = ATBO program (projected ATBO, by year, over engine life)
COH(j) = cost of jth overhaul
FLYPRG = engine flying program (projected flying hours, by year, over engine life)
LIFOHC = engine lifetime overhaul cost
NLOH = number of lifetime overhauls
OHAGE(j) = engine age at time of jth overhaul
TECH = engine technical characteristics

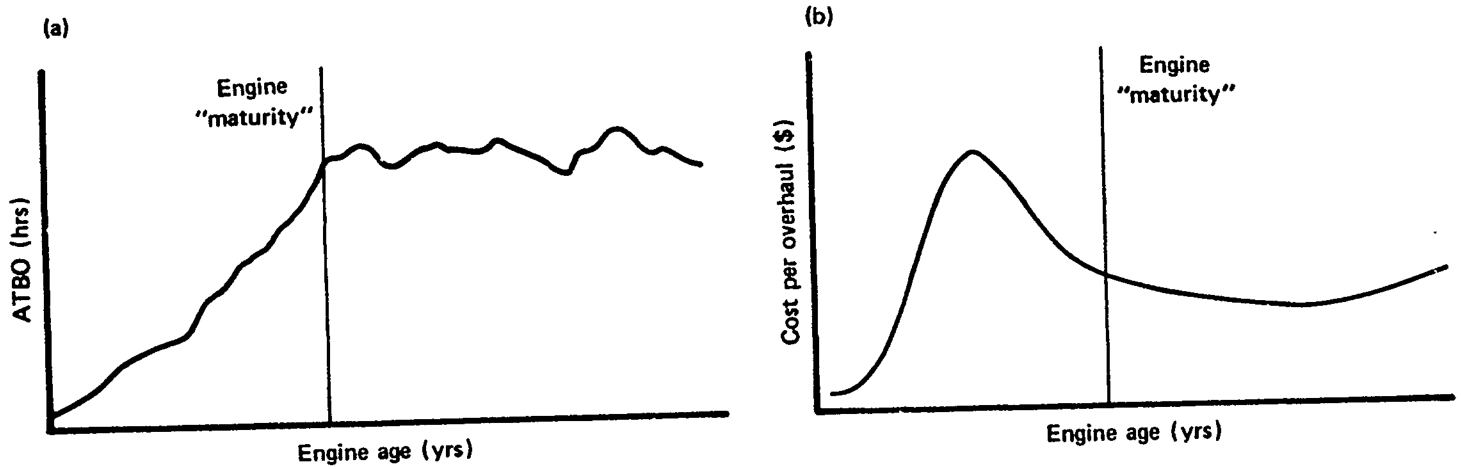

Fig. 1—ATBO and cost to overhaul as a function of engine age

Engine depot repair cost presents a slightly different problem from overhaul cost. Whereas overhauls tend to be somewhat standard for a given engine model, repairs can be quite diverse in both type and frequency. Thus, engine depot repair cost would appear to be most logically estimated on the basis of an average annual cost per installed engine. Additionally, the average cost to repair is believed to vary in a manner similar to engine overhaul cost (see Fig. 1(b)). Based on these observations, a parametric model for an engine's lifetime depot repair cost might take the following form:

(vi) REPFRC(i) = f(TECH, APPLIC, FLYPRG, AGE(i))

(vii) AVGCTR(i) = f(TECH, APPLIC, AGE(i))

(viii) ENGDRC(i) = REPFRC x AVGCTR(i)

(ix) $$\mathrm{LIFDRC} = \sum_{i=1}^{n} \mathrm{ENGDRC(i)}$$

where

AGE(i) = engine age in year i
APPLIC = engine application characteristics (average characteristics)
AVGCTR(i) = average cost per repair in year i
ENGDRC(i) = annual depot repair cost per installed engine
FLYPRG = engine flying program (projected flying hours, by year, over engine life)
LIFDRC = engine lifetime depot repair cost
n = number of years in engine life cycle
REP.RC(i) = fraction of installed engines returned to depot for repair in year i
TECH = engine technical characteristics

While the preceding formulation is conceptually valid, it has two difficulties which preclude its testing at this time. First, cost data are available for only three years (1975, 1976, and 1977). Given an engine life of 15 years or more, such limited longitudinal data cannot be viewed with any degree of confidence. Second, the shape of the overhaul cost and repair cost curves (see Fig. 1(b)) represents a degree of sophistication considerably beyond the norm that now exists

at DSARC II. Consequently, the following simplified model will be tested instead. It assumes a "mature" engine;* that is, one which is past all the problems associated with the introduction of a new engine into the fleet.

Overhaul Cost

(x) ATBO = f(TECH, APPLIC)

(xi) NLOH = (n x ANNFHR/ATBO) - 1

(xii) AVGCOH = f(TECH, APPLIC)

(xiii) LIFOHC = NLOH x AVGCOH

Depot Repair Cost

(xiv) ANNCTR = f(TECH, APPLIC)

(xv) LIFDRC = n x ANNCTR

where
ANNCTR = annual cost to repair per installed engine
ANNFHR = annual flying hours
APPLIC = engine application characteristics
ATBO = average time between overhaul
AVGCOH = average cost to overhaul
LIFDRC = engine lifetime depot repair cost
LIFOHC = engine lifetime overhaul cost
n = number of years in engine life cycle
NLOH = number of lifetime overhauls
TECH = engine technical characteristics

Table 4 shows specific explanatory variables used in our quantitative analysis to relate ATBO, AVGCOH, and ANNCTR to technical, size, application, and other explanatory variables.

The ATBO, the average cost to overhaul, and the annual cost to repair should be related to engine technical characteristics such as turbine inlet temperature, the thrust-to-weight ratio, the total

*A mature engine is defined as an engine which has been in the fleet at least 5 years.

Table 4

POTENTIAL EXPLANATORY VARIABLES FOR ENGINE
DEPOT OVERHAUL AND REPAIR COST ELEMENTS

Explanatory Variables	Source	Samples #1	Cost Element: Average Time Between Overhaul	Cost to Overhaul	Annual Cost to Repair
TECHNICAL/PERFORMANCE					
Turbine inlet temperature (degrees Rankine)	Gray Book#2	1	X	X	X
Thrust-to-weight ratio	Table entries	1	X	X	X
Pressure term (psf)	N-1242,Tbl 11#3	1	X	X	X
Specific fuel consumption (psf)	Gray Book	1	X	X	X
Maximum Mach number	Gray Book	1	X	X	X
Removal rate (usage removals per 1000 hours)	AFLC Form 992	1	X		X
Selling price at 1000th unit ($ 1978)	N-1242,Tbl 49	1	X	X	X
SIZE					
Weight (lbs)	Gray Book	1		X	X
Maximum thrust (lbs)	Gray Book	1		X	X
Military thrust (lbs)	Gray Book	1		X	X
APPLICATION					
Annual engine sorties	HQ USAF/PAXRB	1	X		X
Mission designator (bomber-cargo/fighter-attack)	Assigned	1	X		X
Fighter/attack designator (air-to-air/air-to-ground)	R-2249,Tbl A1#4	3	X		X
Single engine designator (multi/single)	WSCRS	1	X		X
Reserve/Guard fraction	AF Plng Data	1	X		X
MISCELLANEOUS					
Turbofan designator (yes/no)	Nomenclature	1		X	X
Manufacturer designator (GE/P&W)	Nomenclature	2	X	X	X
Type maintenance indicator (organic/contract)	WSCRS	1		X	X

#1 Indicates extent of variable applicability in terms of sample: (1) Basic sample (all turbojet and turbofan engines in data base; turboprop and reciprocating engines are excluded). (2) Pratt & Whitney and General Electric engines only. (3) Engines on fighter/attack aircraft only.

#2 Gray Book is USAF Propulsion Characteristics Summary, Air Force Guidebook Number Three.

#3 Future V/STOL Airplanes: Guidelines and Techniques for Acquisition Program Analysis and Evaluation, J. R. Nelson, J. R. Gebman, J. L. Birkler, R. W. Hess, P. Konoske-Day, W. H. Krase, The Rand Corporation, N-1242-PA&E, October 1979.

#4 Measuring Technological Change in Jet Fighter Aircraft, W. L. Stanley, M. D. Miller, The Rand Corporation, R-2249-AF, September 1979.

pressure acting on critical engine components, the engine's specific fuel consumption, and the maximum Mach number. Generally speaking, the higher the values associated with these variables, the higher the level of technology which is embodied in the engine and the greater the degree of part complexity (in terms of configuration and material composition). In turn, this increased part complexity usually leads to a greater incidence of part failure as well as an increased cost to overhaul/repair.

Other technical characteristics which may affect engine depot overhaul and repair costs are the removal rate and the selling price. Intuitively, higher removal rates should be associated with shorter ATBOs and higher annual repair costs. Similarly, more expensive engines tend to be more technologically advanced than less expensive engines, and therefore less reliable and more costly to overhaul/repair.*

The number and size of engine parts can be expected to influence maintenance costs. Depot maintenance costs for turbofan engines should be higher than those for turbojet engines because of the additional number of parts associated with the fan section. Similarly, larger engines have larger parts and subassemblies which may cause greater handling difficulties and a more extensive inspection effort. Engine weight and thrust are assumed to be indicators of size.

The application variables--sortie rate, mission designator, fighter/attack designator, single-engine designator, and the fraction of engines operated by Guard and Reserve units--should affect the ATBO and the annual cost to repair. Takeoff and landing cause full-throttle excursions which, as stated earlier, contribute to cyclic failure. Thus, higher sortie rates should be associated with shorter overhaul intervals and higher repair costs.

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*It is of course possible that, other things being equal, higher selling prices reflect measures undertaken to improve reliability and maintainability. Generally speaking, however, we do not feel this to be a significant factor, particularly with respect to our data base, which consists largely of engines developed prior to the current emphasis on reliability and maintainability issues.

Excluding takeoff and landing, the engine power level profile (engine power level versus mission time) for a bomber/cargo aircraft will be much more constant than for a fighter/attack aircraft. Thus, the fighter/attack aircraft are going through many more throttle excursions than bomber/cargo aircraft, thereby resulting in higher levels of thermal and cyclic fatigue. A further refinement of mission effects, applicable only to fighter and attack aircraft, suggests that engines on aircraft with an air-to-ground mission will have shorter overhaul intervals and higher overhaul and repair costs than engines on aircraft with an air-to-air mission because of the higher stresses placed on engines operating at low altitude.

Because an engine failure can be catastrophic on a single-engine aircraft, the engine of such an aircraft may be subjected to more frequent and thorough inspections and to more conservative maintenance policies, and cost more to overhaul, than a similar engine on a multiengine aircraft.

Engines on aircraft operated by Guard and Reserve units may have higher depot maintenance costs than engines on aircraft operated by active units. Factors that could cause this include the typically greater age of aircraft operated by the reserves. Another possible explanation is that some Guard and Reserve pilots fly a specific aircraft type less frequently than active duty pilots and therefore may make more throttle adjustments.

Depot maintenance costs may also vary with the manufacturer of an engine. Manufacturers may incorporate unique and consistent design and manufacturing techniques and procedures in their jet engines that result in consistent depot maintenance cost differences.

Finally, the cost to perform a given overhaul/repair action may vary with the organization (depot or contractor) performing the work. Depots are bound by federal government regulations and policies and this may affect maintenance costs.

One general area which, with the exception of the performing organization designator, is prominent by its absence from our analysis is maintenance policy, which includes such things as:

- o Inspection interval or technique
- o Health monitoring program
- o Quantity and sophistication of base and depot support equipment
- o Engine modularity

Such factors were omitted from the analysis for two reasons. First, consistent and sound performance measures could not be developed. Second, even if consistent measures could have been developed, many of the variables would lack sufficient data for a parametric analysis because of their relative newness (e.g., engine modularity and health monitoring).

Component Repair

Component repair costs will be estimated as annual costs per possessed aircraft. The repair costs for airframe components and for engine components and accessories are expected to be driven by the same set of factors that influence airframe rework and engine overhaul and repair costs. Thus, the variables listed in Tables 3 and 4 were used in the analysis of these categories of component repair as well as in the analysis of costs for whole airframes and engines.

Avionics depot repair cost will be estimated as an annual cost per possessed aircraft utilizing technical and application characteristics associated with the aircraft's avionics suite. It should be noted that identifying "the" avionics suite for a mature MDS is a formidable task. A suite changes continuously over time, but not uniformly for all aircraft in the series. Thus, the determination of values for avionics suite characteristics is subject to some uncertainty.

Table 5 groups specific explanatory variables investigated in our analysis according to the aspect described: size, complexity, and application.

Weight is a measure of size, and other things being equal, the greater the size, the greater the repair cost. Given the

Table 5

POTENTIAL EXPLANATORY VARIABLES FOR AVIONICS COMPONENT REPAIR

Variable	Source
SIZE (weight)	Unpublished Rand data
PERFORMANCE/COMPLEXITY	
Capability (aircraft first flight date)	SAC Charts#1
Number of "black boxes"#2	SAC Charts
Number of functions	SAC Charts
Suite procurement cost ($)	Published#3,#4 and unpublished Rand data
Mean time between OFM demands (flying hours)	R-2552-PA&E#4
Combat designator (combat/noncombat)	Assigned
All-weather capability (yes/no)	Unpublished Rand data
Mission group designator (bomber, cargo, fighter/attack, reconnaissance, trainer)	Assigned
APPLICATION	
Annual flying hours per aircraft	WSCRS
Annual sorties per aircraft	HQ USAF/PAXRB
Percentage of unique items (%)	R-2552-PA&E

#1 USAF Standard Aircraft/Missile Characteristics, Air Force Guide Number Two.

#2 "Black boxes" refers to individual pieces of avionics equipment, which are generally designated by AN (Army-Navy designation) number.

#3 An Estimating Relationship for Fighter/Interceptor Avionic System Procurement Cost, C. Teng, The Rand Corporation, RM-4851-PR, February 1966.

#4 Estimating USAF Aircraft Recoverable Spares Investment, K. J. Hoffmayer, F. W. Finnegan, Jr., and W. H. Rogers, The Rand Corporation, R-2552-PA&E, August 1980.

conglomeration of integrated circuits, array antennae, discrete devices, magnetic amplifiers, etc., which exist for current inventory aircraft, the credibility of weight as a measure of avionics repair cost is clearly questionable. However, it is doubtful that a size measure exists that does not have this or a similar problem.

We were not able to determine a fully satisfactory capability measure which applies to the suite as a whole, so aircraft first flight

date is taken as a proxy. This assumes that capability is increasing uniformly over time. Another indicator of capability may be the number of individual black boxes in the suite. A higher number of black boxes is also associated with a higher part count and a greater degree of system integration than a lower number of black boxes. In turn, part count and the degree of system integration are felt to be significant influences on repair cost. The number of functions a suite performs is a measure of capability which differs from the number of black boxes in that the number of functions reduces the impact of redundant black boxes. Functions which will be counted are as follows:

Communication/Identification
Navigation
Bomb Navigation/Fire Control
Penetration Aids/ECM
Reconnaissance
Controls/Displays/Instrumentation

Suite procurement cost reflects the types of materials used and the complexity of manufacturing tasks involved in producing the suite components.

Avionics depot repair workload is influenced by the suite Organization and Field Maintenance (OFM) demand rate. As the suite OFM demand rate increases, the depot's share of that workload should also increase.

Several aircraft characteristics may affect the cost of avionics depot repair. Intuitively, aircraft intended for combat should have more complex avionics and consequently should be more expensive to repair. Because an all-weather capability implies a more complex navigation function, aircraft with such a capability should be more expensive to repair. Avionics components on lower-performance aircraft (e.g., bombers and transports) are subject to lower levels of vibration and acoustic noise, are not packed as densely, and operate in a more benign temperature environment than do avionics

components on higher-performance aircraft (fighters and attack aircraft). The mission type also captures to some extent the average sortie length and the total hours flown. Higher sortie rates are generally associated with higher repair costs since as the number of sorties increases, the number of times the components are switched on and off increases, which in turn leads to a greater incidence of failures. Similarly, a higher number of annual flying hours should lead to more failures per year. Suite depot repair cost should also be affected by the degree of component commonality among aircraft. Greater degrees of commonality should result in greater levels of repair-line standardization and therefore lower repair cost.

There are several other factors which we believe could influence avionics depot repair cost but which were not tested, primarily because of definitional problems: Unambiguous definitions applicable at the suite level could not be developed. For example, conventional wisdom suggests that as an avionics system matures, its failure rate and repair cost should decrease. Because an aircraft's avionics suite changes constantly, however, it is extremely difficult to determine a single value for suite age. An aircraft's avionics depot repair cost should also be influenced by whether or not the suite represents a revolutionary or evolutionary technology change. Revolutionary change may occur in components (e.g., the change from solid state devices to integrated circuits), in the degree of system complexity (i.e., the component count), in system philosophy (e.g., functional integration vs. functional self-sufficiency), and in diagnosis and repair philosophy (e.g., inclusion of self-test functions). While revolutionary change may be beneficial in the long run, in the short run it is usually associated with more unreliable operation. Additionally, since a sizable portion of maintenance action time is normally attributable to diagnosis, the "ease" of diagnosis should also affect repair cost.

There are two final concepts which will not only not be investigated because of definitional ambiguity but for which the direction of change in cost can not be postulated with any certainty.

The first is the level of technology--discrete device or integrated circuit. Integrated circuits are probably more reliable than discrete devices but may be more expensive to repair. The second is the degree of functional integration. Suites with greater degrees of functional integration are generally regarded as more difficult to diagnose and therefore more expensive to repair. On the other hand, suites with greater degrees of self-sufficiency should also be more expensive to repair because of the additional components.

General Variables

Consideration was given to identifying variables related to policies and procedures involving different labor and overhead rates at facilities performing similar work.

The direct labor rate charged by an ALC for a given category of work is related to the total amount of work in that category that the ALC performs and to the mix of skills possessed by the organizational unit doing the work.

Overhead rates charged by an ALC vary with the total number of ALC personnel, the number of personnel performing operations overhead and G&A tasks, and the total number of personnel on the base at which the ALC is located. The total "Other Indirect" cost is also known as "Operations Overhead," which in total varies with direct workload. The rate varies with component class and type of maintenance activity. The G&A total is essentially fixed.

Total costs for similar work packages differ significantly among contract maintenance facilities and between contract and organic facilities.

Different labor rates apply to different component classes and different categories of maintenance activity, due to different mixes of skills.

Unfortunately, the WSCRS data files from which our working data base was derived do not identify the organization performing the reported work. As a result, variables related to organizational entities could not be defined.

COMMON ASPECTS OF ANALYTICAL APPROACH

Estimating equations were developed in this study for each of the following categories of depot maintenance activity: (1) airframe rework, (2) engine overhaul and repair, (3) airframe component repair, (4) engine component and accessory repair, and (5) avionics component repair. The data base was divided into separate files for this purpose. Some aspects of the analysis are common to all categories and are discussed below. Section V presents the results and aspects of the analysis that were peculiar to each category.

Multiple regression analysis was the technique used to examine the relationships between cost and potential explanatory variables. Only one equation form was used--logarithmic-linear:

$$\ln(Y) = a + b \ln(x_1) + c \ln(x_2) + \ldots,$$

where Y is the dependent variable, x_1, x_2, etc., are independent variables, and a, b, c, etc. are coefficients to be derived by regression analysis. The logarithmic form was selected because it has the advantage that the assumption of normal distribution of error about the linearized equation leads to an estimating equation with constant percentage error. The alternative equation forms (linear and exponential) lead to constant absolute dollar errors. Since many variables in the data base span large ranges of values, constant percentage errors were considered more appropriate. The analysis showed that a few variables might be handled better by some other transformation, such as a logit transformation, but this was left as a subject for future investigation.

Potential explanatory variables for each depot maintenance activity were grouped into three major categories: size, technical/performance, and application/utilization. (Airframe activities

possessed a third category: policy.) Ideally, an estimating relationship would incorporate at least one variable from each category. Practically, however, it proved difficult to find such estimating relationships. Furthermore, equations incorporating only an application (or policy) variable would not be particularly useful since the hardware itself would not be defined. Consequently, acceptable equations incorporating size and/or technical/performance variables were determined first, and then application (or policy) variables were added where they were significant. In almost all cases, the number of possible variable combinations was small enough that all possible regressions could be run and examined to see the effects of each variable.

The estimating relationships were evaluated on the basis of statistical quality and intuitive reasonableness. Variable significance was utilized as an initial screening device to reduce the number of estimating relationships requiring closer scrutiny. Normally, only those equations for which all variables were significant at the 5 percent level (in a one-sided t-test) were documented in this report. Occasionally this criterion was relaxed in order to provide a useful comparison with an equation that meets the criterion.

Other statistical measures used in the analysis include the coefficient of determination, the standard error of estimate, and the F-statistic. The coefficient of determination was used to indicate the degree of association between the independent and dependent variables in the equation. The standard error was used to indicate the degree of variation of the data about the regression line. It is given in logarithmic form in this report but may be converted to a percentage of the predicted value by performing these calculations:

$$e^{+SEE} - 1$$

$$e^{-SEE} - 1$$

For example, a standard error of 0.30 yields standard error percentages of +35 and -26 percent. The F-statistic was used to determine whether or not the explanatory variables in an estimating relationship are collectively related to the cost variable. Those equations for which the probability of the null hypothesis being true (i.e., the set of independent variables being unrelated to the dependent variable) is greater than 0.05 are identified when the equations are presented.

Collinearity in two-variable estimating relationships was avoided by not testing explanatory variable combinations whose correlation coefficient was 0.7 or greater. Collinearity in estimating relationships incorporating more than two explanatory variables was avoided by rejecting any result for which one explanatory variable's correlation with the other equation variables was 0.7 or greater. A few equations that did not meet this criterion were derived in the course of the analysis. A review of these gives the impression that a thorough analysis using a higher critical value, such as 0.8 or 0.9, would not be likely to produce equations more useful than those arrived at with the 0.7 criterion.

Plots of equation residuals* were given cursory examinations in order to identify obvious patterns and to identify additional explanatory variables which might help to explain part of the remaining variance. Observations which were believed to be outliers were eliminated prior to statistical analysis.

Finally, the estimating relationships were reviewed for reasonableness. All estimating relationships for which the sign of the variable coefficient is not consistent with a priori notions, or for which the magnitude of a coefficient produces results which do not seem credible, have been identified in the presentation of results.

The acceptable estimating equations are presented in tabular form for each cost category. The equations are presented in their

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*The most frequently used plots were residuals vs. predictions and residuals vs. time (aircraft first flight date or engine MQT).

exponential form,* although the regression analyses were performed using the log-linear form discussed above. Statistics presented with the equations include: the coefficient of determination (R square), the standard error of the estimate (SEE), the F-statistic (F), and the sample size (N). The significance level for each variable in an equation is shown directly below the mnemonic for the variable. Additionally, a comment column provides space for information regarding other aspects of the estimating relationships such as the reasonableness (sign and magnitude) of the variable coefficients.

In developing a recommended set of depot maintenance cost estimating relationships, we initially tried to select relationships which satisfied the following conditions:

- Each variable is significant at the 5 percent level.
- The equation as a whole is significant at the 5 percent level.
- Individual elements of the equation are credible.
- Residual plots are free of systematic patterns that indicate possible bias in the estimating relationship.

Once these initial conditions were satisfied, the objective was minimization of the standard error of estimate. Tradition suggests that a "good" estimate will be within ±20 percent of the actual cost. As will be seen, however, few of the estimating relationships documented herein come close to this objective.

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*If the log-linear form is used for a regressi[illegible] uation, the expected cost is given by an equation of the form

$$Y = (e^a x_1^b x_2^c \ldots)e^z$$

where z = v/2 and v is the actual variance of the error term in the log-linear equation. Although the actual variance is unknown, it can be approximated by the square of the standard error of estimate, SEE.

IV. DEVELOPMENT OF ESTIMATING EQUATIONS

Separate analyses were conducted for data pertaining to the categories of airframe rework, engine overhaul and repair, airframe component repair, engine component and accessory repair, and avionics repair. An alternative approach was also evaluated: estimating annual depot maintenance cost as a total that includes the costs of these separate categories without dealing with them individually. All the results are presented in this section. Some data plots are included here to provide an understanding of the scope of the data base. Additional plots are assembled in App. E.

AIRFRAME REWORK ANALYSIS

Depot-level airframe rework cost was estimated on the basis of an annual cost per aircraft. Analysis of other forms of the dependent variable (total annual fleet cost and cost per visit/number of visits) is discussed in App. F. The most important descriptive data for these aircraft are shown in Table 6. Values for other candidate explanatory variables may be found in App. D.

Data Base

Data for 35 different MDS aircraft are provided in Table 6. However, the A-10A, though shown in the table, was not included in the analysis because it is so new that no significant depot costs were accumulated during the years covered by the data base. The range of size and technical characteristics covered by the remaining 34 aircraft is shown below:

Characteristic	Data Base Range
Empty weight (lbs)	4067-320,085
Maximum speed (knots)	325-1434
Dynamic pressure at maximum speed (psf)	178-1566
Maximum load factor (g's)	2.0-8.7

Table 6

AIRFRAME REWORK COSTS: AVERAGES FOR 1975-1977

(Costs in 1978 dollars)

MDS	Annual Fleet Cost ($000)	Annual Cost per Aircraft ($)	Cost per Visit ($)	Annual Depot Production Quantity	PDM?	Inven-tory	Most Represen-tative Series?
A-7D	4,778	13,090	51,932	92	P	365	Y
A-10A	3	94	---	0	N	29	Y
A-37	1,238	10,952	4,139	299	P	113	Y
B-52D	3,011	33,828	143,368	21	Y	89	N
B-52G	39,722	245,195	630,501	63	Y	162	Y
B-52H	20,551	230,913	587,178	35	Y	89	N
C-5A	26,469	407,222	715,391	37	P	65	Y
C-130E	10,634	37,843	98,461	108	Y	281	Y
C-141A	24,826	100,105	206,883	120	Y	248	Y
F-4C	15,254	56,496	98,413	155	Y	270	N
F-4D	20,194	45,482	87,419	231	Y	444	N
F-4E	28,506	47,990	98,980	288	Y	594	Y
F-5B	33	3,667	16,502	2	P	9	N
F-5E	915	17,947	17,602	52	P	51	Y
F-15A	713	8,592	4,542	157	N	83	Y
F-101B	337	3,007	56,127	6	N	112	Y
F-105B	580	17,072	5,635	103	P	34	N
F-105D	2,502	25,275	16,907	148	P	99	Y
F-105F	586	30,830	24,407	24	p	19	N
F-105G	2,121	50,497	151,490	14	P	42	N
F-106A	9,727	55,583	127,987	76	Y	175	Y
F-106B	2,161	58,418	39,299	55	Y	37	N
F-111A	474	5,094	157,904	3	N	93	N
F-111D	766	9,115	85,077	9	N	84	Y
F-111E	820	10,380	410,017	2	N	79	N
F-111F	236	2,775	117,925	2	N	85	N
T-33A	709	3,138	8,059	88	P	226	Y
T-37B	1,045	1,648	8,707	12	N	634	Y
T-38A	2,606	2,915	6,260	460	N	872	Y
T-39A	796	7,207	98,200	8	P	109	Y
FB-111A	209	3,161	34,767	6	N	66	N
KC-135A	16,938	25,938	109,275	155	Y	653	Y
OV-10A	473	5,439	---	0	N	87	Y
RF-4C	15,601	45,089	73,243	213	Y	346	N
TF-15A	233	10,572	11,075	21	N	22	N

NOTE: Y = yes; N = no; P = PDM program for part of data base time period.

Some models of aircraft are represented in the data base by a single MDS, others by four or five different MDSs. In order to evaluate the possible bias caused by this unequal weighting, certain parts of the analysis were repeated with a subsample composed of one series of each model. These "most representative series" aircraft are identified in Table 6.

A plot of the annual rework cost per airframe as a function of empty weight is provided in Fig. 2. An examination of this plot yields the following observations:

- o Rework cost tends to increase as empty weight increases.
- o Data tend to cluster by mission type.

As a result of the latter observation, certain parts of the analysis were repeated with subsamples of fighter/attack and bomber/cargo aircraft. Such divisions have intuitive appeal. The fighters and attack aircraft tend to be small, fast, and maneuverable whereas the bombers and cargo aircraft tend to be large, slow, and not very maneuverable.

Estimating Relationships

Table 3 (Sec. III) lists at least two explanatory variables for each of the explanatory variable categories (size, technical/performance, utilization, and policy). Ideally, an estimating relationship would incorporate one variable from each of the four categories. Practically, however, it proved difficult to find such estimating relationships. Furthermore, equations incorporating only utilization or policy variables would not be particularly useful for predictive purposes since the airframe itself would not be defined. Consequently, acceptable equations incorporating airframe size and technical variables were determined first, and then utilization and policy variables were added where they were significant.

Mnemonics used are as follows:

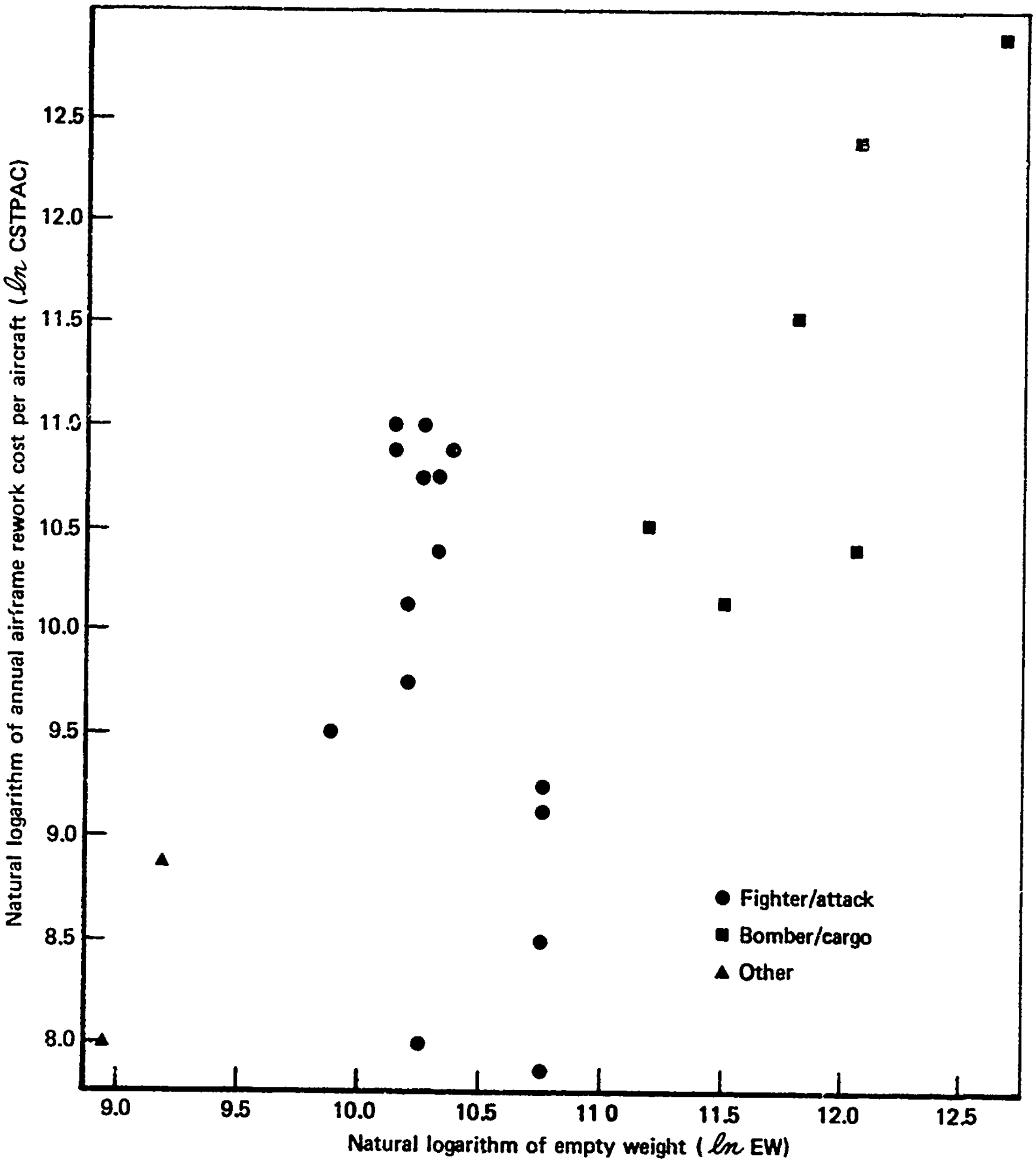

Fig. 2—Variation of annual airframe rework cost per aircraft with empty weight

AFMFGC = airframe manufacturing cost (cumulative average for 100 airframes; millions of 1978 dollars)
AGE = aircraft average age (years)
AFRWKC = annual airframe rework cost per aircraft (1978 dollars)
EW = aircraft empty weight (lbs)
MAINTPCT = percent of airframe rework activity performed organically rather than under contract
PDM = PDM policy (1 = no PDM program, 2 = has a PDM program)
PQ = production quantity (number of depot visits per year)

Total Sample. Estimating relationships incorporating variables significant at the 5 percent level are provided in Table 7. The equations are generally of poor statistical quality. Additionally, other reservations exist. The exponent of the PDM variable is relatively large. This suggests that the annual airframe rework cost for aircraft with PDM programs is approximately 10 times that of aircraft with no PDM programs. However, these equations say nothing about other costs that might be affected by such a decision. A PDM is only one part of a scheduled maintenance program. Avoiding use of a PDM could require larger than normal costs for base-level scheduled inspections. Also, unscheduled maintenance requirements could be larger than otherwise would be expected. Such effects are beyond the scope of this study but must be addressed in any application of these equations.

One should also note that the PQ exponent is counterintuitive: For every doubling of the production quantity, unit costs increase by approximately 35 percent. Finally, one should be aware of the dramatic changes in the empty weight and airframe manufacturing cost exponents when the PDM designator is added.

Most Representative Series. Estimating relationships based on a sample consisting of only one observation per aircraft model are listed in Table 8. The statistical quality of the estimating relationships incorporating empty weight and airframe manufacturing cost improves markedly, while the quality of the two estimating relationships incorporating the PDM variable improves somewhat. On the other hand,

Table 7

AIRFRAME REWORK COST PER AIRCRAFT ESTIMATING RELATIONSHIPS: TOTAL SAMPLE

Equation	R^2	SEE	F	N	Comments
	Statistics				
Size					
$AFRWKC = 2.75\ EW^{0.904}$ (.000)	0.46	1.05	28	34	
Technical, Performance					
$AFRWKC = 44.6\ AFMFGC^{1.06}$ (.001)	0.35	1.12	12	25	
Size/Policy					
$AFRWKC = 0.355\ EW^{0.942}\ PQ^{0.403}$ (.000) (.000)	0.66	0.86	29	33	Sign of PQ exponent
$AFRWKC = 183\ EW^{0.[illegible]}\ PDM^{3.22}$ (.018) (.000)	0.84	0.62	52	23	Exponent magnitude
Technical, Performance/Policy					
$AFRWKC = 2.07\ AFMFGC^{1.22}\ PQ^{0.461}$ (.000) (.000)	0.63	0.86	19	25	Sign of PQ exponent
$AFRWKC = 111\ AFMFGC^{0.602}\ PDM^{3.43}$ (.014) (.000)	0.85	0.59	41	18	Exponent magnitude
Size/Technical, Performance: none					
Size/Utilization: none					
Technical, Performance, Utilization: none					
Size/Technical, Performance/Utilization, Policy: none					

Table 8

AIRFRAME REWORK COST PER AIRCRAFT ESTIMATING RELATIONSHIPS: MOST REPRESENTATIVE SERIES

Equation	Statistics				Comments
	R^2	SEE	F	N	
Size					
$AFRWKC = 0.802\ EW^{1.02}$ (.000)	0.70	0.86	39	19	Exponent magnitude
Technical, Performance					
$AFRWKC = 9.79\ AFMFGC^{1.30}$ (.000)	0.66	0.94	21	13	
Size/Policy					
$AFRWKC = 0.242\ EW^{1.02}\ PQ^{0.267}$ (.000) (.056)	0.74	0.84	21	18	PQ does not meet the 5% significance criterion; sign of PQ exponent; magnitude of EW exponent
$AFRWKC = 44.8\ EW^{.499}\ PDM^{2.72}$ (.027) (.003)	0.87	0.63	30	12	
Technical, Performance/Policy					
$AFRWKC = 2.49\ AFMFGC^{1.30}\ PQ^{.300}$ (.000) (.070)	0.72	0.88	13	13	PQ does not meet the 5% significance criterion; sign of PQ exponent
$AFRWKC = 27.0\ AFMFGC^{.861}\ PDM^{2.96}$ (.019) (.002)	0.90	0.56	27	9	
Size/Technical, Performance: none					
Size/Utilization: none					
Technical, Performance/Utilization: none					
Size/Technical, Performance/Utilization, Policy: none					

production quantity is no longer significant at the 5 percent level in the two equations reported, a not altogether distressing situation given the counterintuitive nature of its sign.

Fighter/Attack Sample. No estimating relationships incorporating variables meeting our 5 percent significance level criterion could be identified for the fighter/attack sample. This result is not too surprising since this particular stratification eliminates much of the variation in the size and performance variables.

Bomber/Cargo Sample. Only a single estimating relationship incorporating a variable meeting our 5 percent significance level criterion could be identified. The equation, based on airframe manufacturing cost, is as follows:

$$AFRWKC = 4.81 \underset{(.020)}{AFMFGC^{1.39}}$$

$$(R^2 = 0.60,\ SEE = 0.77,\ F = 8,\ N = 7)$$

Summary. The analysis of annual airframe rework cost per aircraft can be summarized as follows:

- Surprisingly few estimating relationships were identified in which all equation variables met our 5 percent significance level screening criterion.
- Of those estimating relationships which did meet our initial screening criterion, most were of dubious statistical quality.

The selection of a recommended estimating relationship would seem to focus on the following equations:

Total Sample

Equation	R^2	SEE	F	N
$AFRWKC = 183\ EW^{.344}\ PDM^{3.22}$ $(.018)\quad(.000)$	0.84	0.62	52	23
$AFRWKC = 111\ AFMFGC^{.602}\ PDM^{3.43}$ $(.014)\quad(.000)$	0.85	0.59	41	18

Most Representative Series

Equation	R^2	SEE	F	N
$AFRWKC = 44.8\ EW^{.499}\ PDM^{2.72}$ $(.027)\quad(.003)$	0.87	0.63	30	12
$AFRWKC = 27.0\ AFMFGC^{.861}\ PDM^{2.96}$ $(.019)\quad(.002)$	0.90	0.50	27	9

All equations include the highly relevant PDM variable. However, as mentioned previously, the equations say nothing about base-level costs that might be affected by a PDM/no-PDM decision.

ENGINE OVERHAUL AND REPAIR ANALYSIS

The estimation of engine lifetime overhaul cost requires the development of two estimating relationships: the average time between overhaul (ATBO) and the average cost to overhaul. Engine lifetime repair cost will be estimated on the basis of an annual cost to repair per installed engine. ATBO, average cost per overhaul, and average annual repair cost data to be used in the analyses are summarized in Table 9. Candidate explanatory variable values may be found in App. D.

Data Base

An examination of Table 9 indicates that the T76 and IO-360 C/D apparently incurred no overhaul or repair costs during the 1975-1977

Table 9

SUMMARY ENGINE DATA BY TMS: AVERAGES FOR 1975-1977

(Costs in $ 1978)

			Overhaul Data			Repair Data		
Engine	Installed Engines	Annual Flying Hours per Engine	Average Time Between Overhaul (ATBO)	Average Cost per Overhaul ($)	Average Number of Annual Overhauls	Average Cost per Repair ($)	Average Number of Annual Repairs	Average Annual Repair Cost per Installed Engine
J33-A-35	207	345	3260	2,373	38	8,850	5	207
J57-P-13A/B	87	258	1560	3,863	1	---	---	---
-19W/29WA	1018	263	2978	36,283	62	3,010	28	83
-21A/B	356	227	431	32,552	51	[illegible]	51	1056
-23B	65	285	609	---	---	[illegible]	---	---
-43WB	1601	407	2904	29,578	156	2,880	106	191
-55/55A	218	300	1246	32,560	26	21,000	5	482
-59W	2613	333	2377	35,220	257	25,400	3	29
J60-P-3/3A	261	934	2210	8,885	53	29,700	1	114
J65-W-5F	77	395	792	17,280	42	---	---	---
J69-T-25	1397	437	3032	4,255	260	840	1	1
J75-P-17	199	343	918	30,618	49	16,000	22	1771
-19/19W	194	226	921	30,998	43	8,640	40	1782
J79-GE-15	2112	258	1057	38,883	462	3,550	111	187
-17/17A	1286	252	1048	31,423	267	5,180	52	209
J85-GE-5H	1831	400	2207	10,231	175	3,140	1	2
-13	23	298	1182	8,499	3	6,920	1	301
-17A	280	226	1528	---	---	---	---	---
-21	201	194	176	---	---	9,700	5	241
TF30-P-3	313	247	530	51,380	128	2,400	270	5265
-7	116	313	523	42,602	51	14,600	32	4016
-9	147	236	552	57,702	22	17,000	20	2307
-100	174	256	342	64,122	77	11,200	51	3292
TF33-P-3	735	428	2715	29,250	53	3,000	44	180
-5	100	675	3423	28,558	10	70,600	2	1412
-7/7A	1095	1068	6962	26,394	119	5,460	40	200
-9	103	764	5350	26,885	9	28,000	2	543
TF34-GE-100	108	214	192	---	---	---	---	---
TF39-GE-1/1A	277	631	1602	44,324	46	14,700	38	2018
TF41-A-1/1A	354	299	355	88,287	140	14,268	435	17,532
F100-PW-100	338	157	180	55,561	3	26,800	19	1506
-23A	338	157	155	---	---	7,150	19	402
-23B	338	157	183	57,347	3	32,700	21	2030
-23C	338	157	172	16,734	6	6,980	4	83
-23F	338	157	272	12,039	4	16,700	[illegible]	99
-23G	338	157	169	2,645	4	3,460	[illegible]	61
T56-A-7B^a	1596	574	2661	11,592	287	3,210	[illegible]	107
-9B^a	549	413	1814	13,990	98	1,430	68	177
-15	542	524	2588	14,622	64	2,860	19	100
G56-A-7B^a	1032	670	2636	---	---	890	1	1
-9B^a	547	419	1628	12,117	123	1,170	44	94
-15^a	1276	481	1368	8.938	436	1,280	60	60
T76-GE-10A	92	339	1363	---	---	---	---	---
-12A	90	347	1651	---	---	---	---	---

^{a}T56 gearbox.

NOTE: --- = No data reported in WSCRS.

time period and were therefore eliminated from the sample. This left the T56 as the only turboprop in the sample. Therefore, the T56 was also eliminated from further analysis. Two engines (the F100 and the TF34) were eliminated from the sample because they were phasing into the inventory during the 1975-1977 time period and therefore did not meet the mature engine criteria. Finally, several engines were eliminated from the sample to reduce the problem of engine series weighting (e.g., the J57 has seven series, the J60 has one). Thus, for those engines with multiple series, a particular series was retained only if it represented a significant difference in performance or application from other series of that engine model.

The final sample consisted of the following 17 engines:

J33-A-35	J79-GE-15
J57-P-19W/29WA	J85-GE-5H
-21A/B	TF30-P-3
-43WB	-100
-59W	TF33-P-3
J60-P-3/3A	-7/7A
J65-W-5F	TF39-GE-1A
J69-T-25	TF41-A-1/1A
J75-P-17	

These engines cover a fairly wide range of technical and size characteristics as shown below:

Characteristic	Data Base Range
Turbine inlet temperature (°R)	19[illegible]-2810
Pressure term (psf)	3400-65,840
Specific fuel consumption (lbs/hr/lb)	0.315-1.140
Weight (lbs)	367-7475
Military thrust (lbs)	1,025-40,805

Plots of ATBO, overhaul cost, and annual repair cost as a function of the engine pressure term* are provided in Figs. 3, 4, and 5, respectively. An examination of these plots yields the following observations:

- For a given mission type, the overhaul interval generally decreases as the pressure term increases.
- The average cost per overhaul increases fairly uniformly as the pressure term increases.
- The annual cost to repair generally increases as the pressure term increases, but appears unaffected by the aircraft mission type.

Estimating Relationships

Table 4 (Sec. IV) lists several variables for each of the explanatory variable categories (technical/performance, size, and application). Ideally, an estimating relationship would incorporate one variable from each of the three categories. Practically, however, it proved difficult to find such estimating relationships. Furthermore, equations incorporating only an application variable would not be particularly useful for predictive purposes since the engine itself would not be defined. Consequently, acceptable equations incorporating engine performance and size variables were determined first, and then application variables were added where they were significant.

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*The engine pressure term was selected as the plot parameter because it was one of the more successful explanatory variables throughout the engine analysis (including accessory and component repair). Additional plots for these cost categories utilizing other potential explanatory variables may be found in App. E.

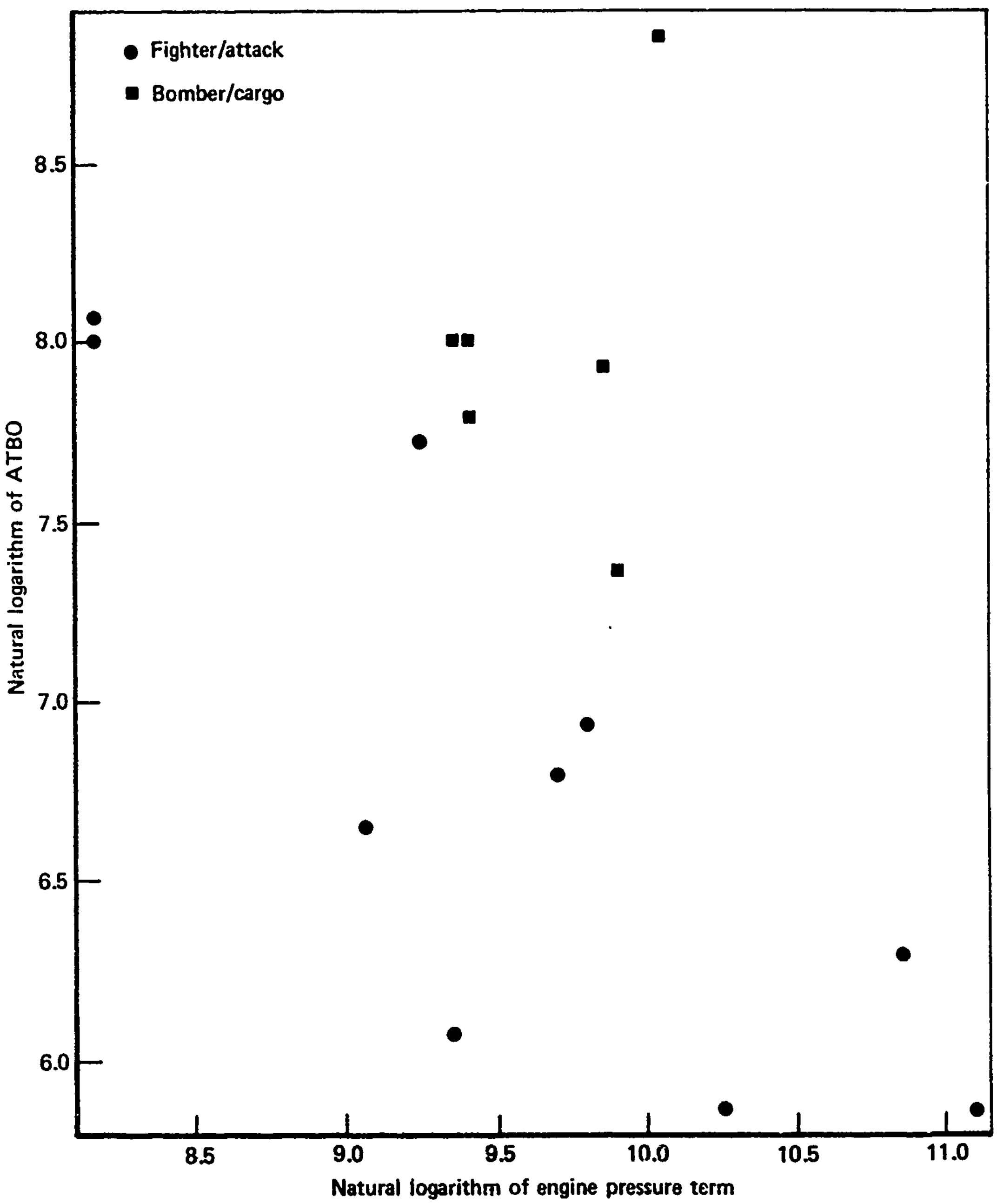

Fig. 3—Variation of ATBO with engine pressure term

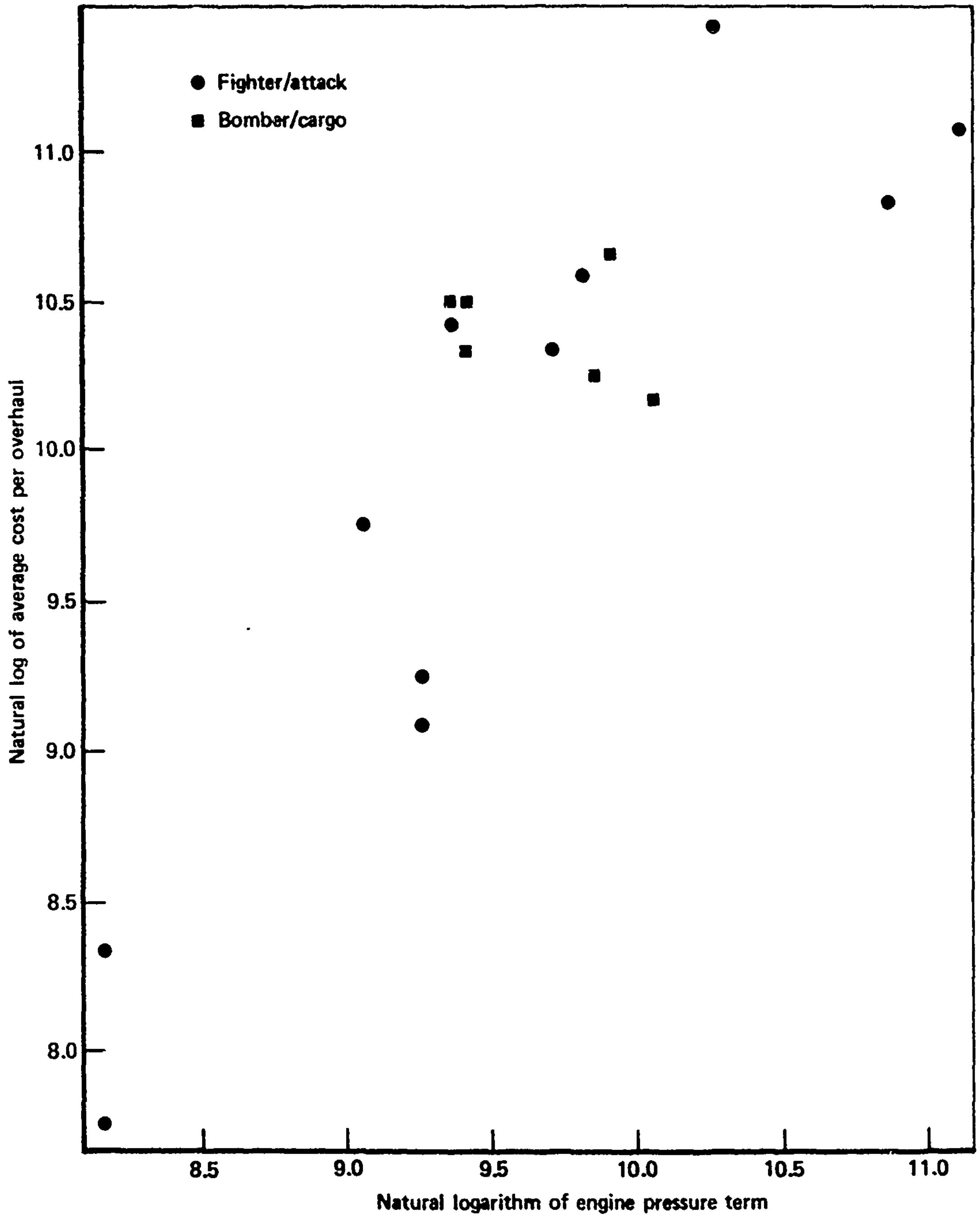

Fig. 4—Variation of overhaul cost with engine pressure term

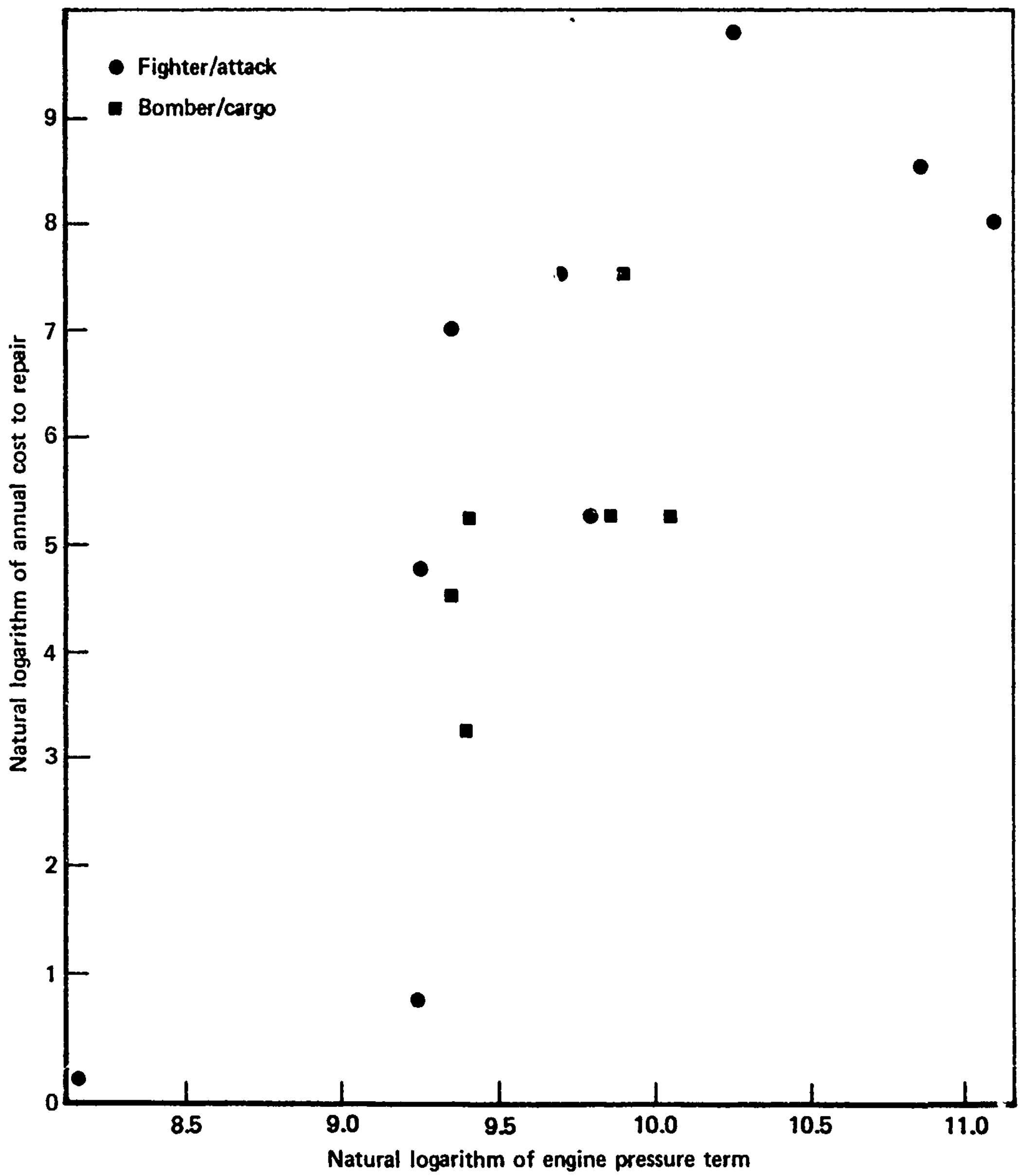

Fig. 5—Variation of annual repair cost with engine pressure term

Mnemonics used are as follows:

ANNCTR = annual cost to repair per engine ($)
ATBO = average time between overhaul (hours)
AVGCOH = average cost per overhaul ($)
MAXTH = maximum thrust (lbs)
MILTH = military thrust (lbs)
MISSDES = mission designator (1 = bomber/cargo; 2 = fighter/attack)
PRSTERM = engine pressure term (psf)
REMRATE = base-level engine removal rate (# per 1000 engine hours)
RSVPCT = percentage of engine operating hours flown by Guard and Reserve Personnel
SELLPR = engine selling price (unit 1000 in 1978 dollars)
SFC = specific fuel consumption (lbs/hr/lb)
SINGDES = single engine designator (multiple = 1, single = 2)
TEMP = turbine inlet temperature (°R)
TYPMTC = type maintenance designator (1 = organic; 2 = contractor)
WT = engine dry weight (lbs)

ATBO. Estimating relationships incorporating variables significant at the 5 percent level are provided in Table 10. The most notable feature of these equations is their generally poor statistical quality. Additionally, the magnitude of the turbine inlet temperature exponent is quite large in every case. Because of the poor statistical quality of these equations, the engine base-level removal rate was separated from the rest of the performance variables and several new combinations were tested. As the statistics indicate, these latter estimating relationships appear to be the best of a poor group.

Average Cost per Overhaul. Costs per overhaul range from under $5,000 to over $85,000. Estimating relationships incorporating variables significant at the 5 percent level are provided in Table 11. Again, the magnitude of the turbine inlet temperature exponent seems unusually large for predictive purposes. However, the equations incorporating the engine pressure term and either weight or military thrust would appear to be acceptable estimating relationships. One of the more interesting aspects of these equations is the magnitude

Table 10

ENGINE ATBO ESTIMATING RELATIONSHIPS

Equation	Statistics R^2	SEE	F	N	Comments
Performance					
$ATBO = 6.69 \times 10^{16}\ TEMP^{-4.05}$ (.026)	.23	.82	4	17	Exponent magnitude; F value
$ATBO = 654000\ PRSTERM^{-.605}$ (.015)	.28	.79	6	17	
$ATBO = 3520\ REMRATE^{-.709}$ (.004)	.39	.73	9	17	
$ATBO = 936000\ SELLPR^{-.473}$ (.025)	.23	.81	5	17	
Size					
None tested since no a priori rationale could be established.					
Performance/Application					
$ATBO = (2.99 \times 10^{16})\ TEMP^{-3.89}$ (.019) $MISSDES^{-1.19}$ (.017)	.45	.71	6	17	Exponent magnitude
$ATBO = (2.24 \times 10^{17})\ TEMP^{-4.19}$ (.017) $SINGDES^{-1.15}$ (.044)	.38	.76	4	17	Exponent magnitude: F value
$ATBO = (2.60 \times 10^{19})\ TEMP^{-4.86}$ (.005) $RSVPCT^{-.124}$ (.008)	.50	.68	7	17	Exponent magnitude
$ATBO = 957000\ PRSTERM^{-.601}$ (.007) $MISSDES^{-1.23}$ (.011)	.51	.67	7	17	
$ATBO = 167000\ PRSTERM^{-.601}$ (.007) $SINGDES^{-1.36}$ (.017)	.48	.69	7	17	
$ATBO = 1570000\ PRSTERM^{-.728}$ (.002) $RSVPCT^{-.129}$ (.004)	.57	.63	9	17	
$ATBO = (5.67 \times 10^{6})\ SELLPR^{-.574}$ (.003) $MISSDES^{-1.50}$ (.003)	.63	.57	9	17	
$ATBO = (1.46 \times 10^{6})\ SELLPR^{-.495}$ (.015) $SINGDES^{-1.17}$ (.040)	.39	.75	4	17	F value
$ATBO = 790000\ SELLPR^{-.476}$ (.016) $RSVPCT^{-1.01}$ (.027)	.42	.73	5	17	
Performance/Reliability					
$ATBO = (6.70 \times 10^{-16})\ TEMP^{-3.99}$ (.007) $REMRATE^{-.703}$ (.001)	.61	.60	11	17	Exponent magnitude
$ATBO = (1.97 \times 10^{6})\ PRSTERM^{-.670}$ (.001 $REMRATE^{-.765}$ (.000)	.72	.51	18	17	
$ATBO = (3.16 \times 10^{7})\ SELLPR^{-.529}$ (.002) $REMRATE^{-.762}$ (.000)	.68	.54	15	17	

Table 11

ENGINE COST PER OVERHAUL ESTIMATING RELATIONSHIPS

Equation	Statistics R^2	SEE	F	N	Comments
Performance					
AVGCOH = (2.20×10^{-15}) TEMP$^{5.74}$ (.003)	.40	.76	10	17	Exponent magnitude
AVGCOH = 1.24 PRESTERM$^{1.04}$ (.000)	.73	.52	40	17	
AVGCOH = 18400 SFC$^{-1.90}$ (.003)	.41	.76	10	17	Exponent magnitude
AVGCOH = .166 SELLPR$^{.922}$ (.000)	.79	.46	55	17	
Size					
AVGCOH = 68.1 WT$^{.768}$ (.000)	.53	.68	17	17	
AVGCOH = 11.6 MAXTH$^{.839}$ (.000)	.66	.57	29	17	
AVGCOH = 12.1 MILTH$^{.853}$ (.000)	.61	.62	23	17	
Performance/Size					
AVGCOH = (6.34×10^{-11}) TEMP$^{3.77}$ (.012) WT$^{.598}$ (.002)	.68	.58	15	17	Exponent magnitude
AVGCOH = .598 PRSTERM$^{.793}$ (.000) WT$^{.390}$ (.008)	.82	.43	32	17	
AVGCOH = .538 PRSTERM$^{.735}$ (.001) MILTH$^{.412}$ (.017)	.80	.45	29	17	r (PRSTERM, MILTH) = .67
Performance/Application					
None					
Performance/Other					
AVGCOH = (2.13×10^{-6}) TEMP$^{3.08}$ (.036) TYPMTC$^{-1.67}$ (.002)	.67	.58	14	17	Exponent magnitude: TYPMTC exponent reduces cost 70%
AVGCOH = 23.4 PRSTERM$^{.758}$ (.001) TYPMTC$^{-.936}$ (.037)	.78	.47	25	17	Credibility of results: TYPMTC exponent halves cost

of the type-of-maintenance designator, which suggests that contract maintenance is 30 to 50 percent as costly as organic maintenance. Such a result strains credibility and clearly warrants analysis that was beyond the scope of this study before the type-of-maintenance variable is used in cost estimating. Perhaps the observation that most of the contract maintenance engines are on noncombat and reserve/guard aircraft provides a partial explanation.

Annual Cost to Repair. The annual cost to repair has an unusual distribution. Of the 16 observations, 10 are less than $210 per year; 3 between $1000 and $2000 per year; 2 between $3000 and $5000 per year; and 1 over $17,000 per year.* Estimating relationships incorporating variables significant at the 5 percent level are provided in Table 12. The most notable feature of these estimating relationships is clearly the exponent magnitude. Only two equations (WT and PRSTERM/WT) possess variables with exponent magnitudes of less than 2 and in only one case (PRSTERM/WT) are the exponents less than 1.5.

Summary. The estimating relationships listed in Tables 10, 11, and 12 for the three elements of engine overhaul and repair (ATBO, cost per overhaul, and annual repair cost) have two common features: relatively poor statistical quality and large exponents. However, the large exponents would be a serious problem only when extrapolations beyond the range of the data base are made. On the positive side, many variables were found to be significant. Those displaying a degree of consistency across the three cost elements are as follows:

Technical/Performance	Size	Application
TEMP	WT	MISSDES
PRSTERM	MAXTH	SINGDES
SELLPR	MILTH	RSVPCT

*The J65 had no repair costs in 1975-77 and therefore is not included in the analysis.

Table 12

ENGINE ANNUAL COST TO REPAIR ESTIMATING RELATIONSHIPS

Equation	Statistics R^2	SEE	F	N	Comments
Performance					
$ANNCTR = (2.77 \times 10^{-50})\ TEMP^{15.8}$ (.004)	.42	2.09	10	16	Exponent magnitude
$ANNCTR = (3.72 \times 10^{-7})\ PRSTERM^{2.31}$ (.002)	.48	1.97	13	16	Exponent magnitude
$ANNCTR = 995\ SFC^{-4.30}$ (.016)	.29	2.31	6	16	Exponent magnitude
$ANNCTR = (2.41 \times 10^{-9})\ SELLPR^{2.08}$ (.001)	.54	1.85	17	16	Exp [illegible]gnitude
Size					
$ANNCTR = (3.28 \times 10^{-4})\ WT^{1.96}$ (.002)	.48	1.98	13	16	Exponent magnitude
$ANNCTR = (2.52 \times 10^{-7})\ MAXTH^{2.14}$ (.000)	.59	1.76	20	16	Exponent magnitude
$ANNCTR = (5.16 \times 10^{-6})\ MILTH^{2.13}$ (.001)	.53	1.88	16	16	Exponent magnitude
Performance/Size					
$ANNCTR = (3.44 \times 10^{-34})\ TEMP^{10.8}\ WT^{1.47}$ (.015) (.007)	.64	1.70	12	16	Exponent magnitude
$ANNCTR = (2.72 \times 10^{-8})\ PRSTERM^{1.49}\ WT^{1.24}$ (.026) (.028)	.61	1.77	10	16	Exponent magnitude
Performance/Application					
$ANNCTR = (1.47 \times 10^{-53})\ TEMP^{16.6}\ SINGDES^{4.02}$ (.001) (.007)	.64	1.71	11	16	Exponent magnitude
$ANNCTR = (2.62 \times 10^{-55})\ TEMP^{17.3}\ RSVPCT^{.282}$ (.001) (.020)	.58	1.84	9	16	Exponent magnitude
$ANNCTR = (2.26 \times 10^{-30})\ TEMP^{9.90}\ TYPMTC^{-4.11}$ (.028) (.010)	.62	1.74	11	16	Exponent magnitude
$ANNCTR = (1.74 \times 10^{-9})\ PRSTERM^{2.67}\ SINGDES^{4.89}$ (.000) (.000)	.80	1.27	26	16	Exponent magnitude
$ANNCTR = (3.65 \times 10^{-8})\ PRSTERM^{2.55}\ RSVPCT^{.296}$ (.000) (.001)	.66	1.65	13	16	Exponent magnitude
$ANNCTR = 29.8\ SFC^{-7.01}\ MISSDES^{4.52}$ (.001) (.012)	.52	.96	7	16	Exponent magnitude
$ANNCTR = 107\ SFC^{-5.35}\ SINGDES^{4.92}$ (.001) (.013)	.60	1.79	10	16	Exponent magnitude
$ANNCTR = 649\ SFC^{-5.39}\ RSVPCT^{.337}$ (.003) (.015)	.51	1.99	7	16	Exponent magnitude
$ANNCTR = (5.02 \times 10^{-11})\ SELLPR^{2.19}\ SINGDES^{4.16}$ (.000) (.001)	.78	1.33	23	16	Exponent magnitude
Size/Application					
$ANNCTR = (2.48 \times 10^{-7})\ WT^{2.58}\ MISSDES^{3.78}$ (.000) (.007)	.67	1.62	13	16	Exponent magnitude
$ANNCTR = .00321\ WT^{1.54}\ TFDES^{2.76}$ (.008) (.044)	.59	1.83	9	16	Exponent magnitude
$ANNCTR = (1.78 \times 10^{-6})\ MAXTH^{2.50}\ MISSDES^{2.94}$ (.000) (.014)	.72	1.52	17	16	Exponent magnitude
$ANNCTR = (2.44 \times 10^{-6})\ MAXTH^{2.05}\ SINGDES^{3.04}$ (.000) (.017)	.71	1.52	16	16	Exponent magnitude
$ANNCTR = (6.77 \times 10^{-11})\ MILTH^{3.03}\ MISSDES^{4.67}$ (.000) (.000)	.81	1.24	27	16	Exponent magnitude
$ANNCTR = (3.74 \times 10^{-6})\ MILTH^{2.06}\ SINGDES^{3.23}$ (.000) (.017)	.67	1.63	13	16	Exponent magnitude

One possible "set" of estimating relationships which tends to minimize potential problems consists of the following equations:

$$AVGCOH = 0.598\ PRSTERM^{.793}\ WT^{.390}$$

$$ATBO = 957000\ PRSTERM^{-.601}\ MISSDES^{-1.23}$$

$$ANNCTR = 2.72\times10^{-8}\ PRSTERM^{1.49}\ WT^{1.24}$$

AIRFRAME COMPONENT REPAIR ANALYSIS

The category "airframe components" includes structural components, landing gear, utilities, and a variety of other miscellaneous systems. These subcategories are defined in more detail in App. A.

Airframe component repair cost will be estimated on the basis of an annual cost per aircraft. Cost data used in the analysis are summarized in Table 13. Potential explanatory variables are listed in Table 3 (Sec. III). Values for the candidate variables may be found in App. D.

Data Base

The sample used in the airframe component repair analysis is the same sample used in the airframe rework analysis. The A-10A has again been omitted because of the lack of cost data in the 1975-1977 time period. Despite the deletion, the annual airframe component repair cost per aircraft still varies by two orders of magnitude (from $1500 for the OV-10A to $150,000 for the C-5A).

A plot of the annual airframe component repair cost as a function of the aircraft empty weight is provided in Fig. 6. An examination of the plot yields the following observations:

- o Component repair cost tends to increase as empty weight increases.
- o The data points tend to cluster by mission type.

Table 13

AIRFRAME COMPONENT COSTS:
AVERAGES FOR 1975-1977

(Costs in 1978 dollars)

MDS	Cost per Aircraft ($)	Most Representative Series?	PDM?
A-7D	5,035	Y	P
A-10A	389	Y	N
A-37	2,097	Y	P
B-52D	62,521	N	Y
B-52G	70,120	Y	Y
B-52H	73,698	N	Y
C-5A	153,221	Y	P
C-130E	34,165	Y	Y
C-141A	61,791	Y	Y
F-4C	16,022	N	Y
F-4D	16,175	N	Y
F-4E	14,602	Y	Y
F-5B	19,954	N	P
F-5E	3,359	Y	P
F-15A	5,115	Y	N
F-101B	10,436	Y	N
F-105B	14,723	N	P
F-105D	12,239	Y	P
F-105F	19,835	N	P
F-105G	14,895	N	P
F-106A	25,119	Y	Y
F-106B	40,649	N	Y
F-111A	24,729	N	N
F-111D	28,177	Y	N
F-111E	30,635	N	[illegible]
F-111F	29,998	N	N
T-33A	3,376	Y	P
T-37B	1,547	Y	N
T-38A	2,205	Y	N
T-39A	7,351	Y	P
FB-111A	29,518	N	N
KC-135A	12,665	Y	Y
OV-10A	1,539	Y	N
RF-4C	18,432	N	Y
TF-15A	12,195	N	N

NOTE: Y = yes; N = no; P = PDM for part of data base time period.

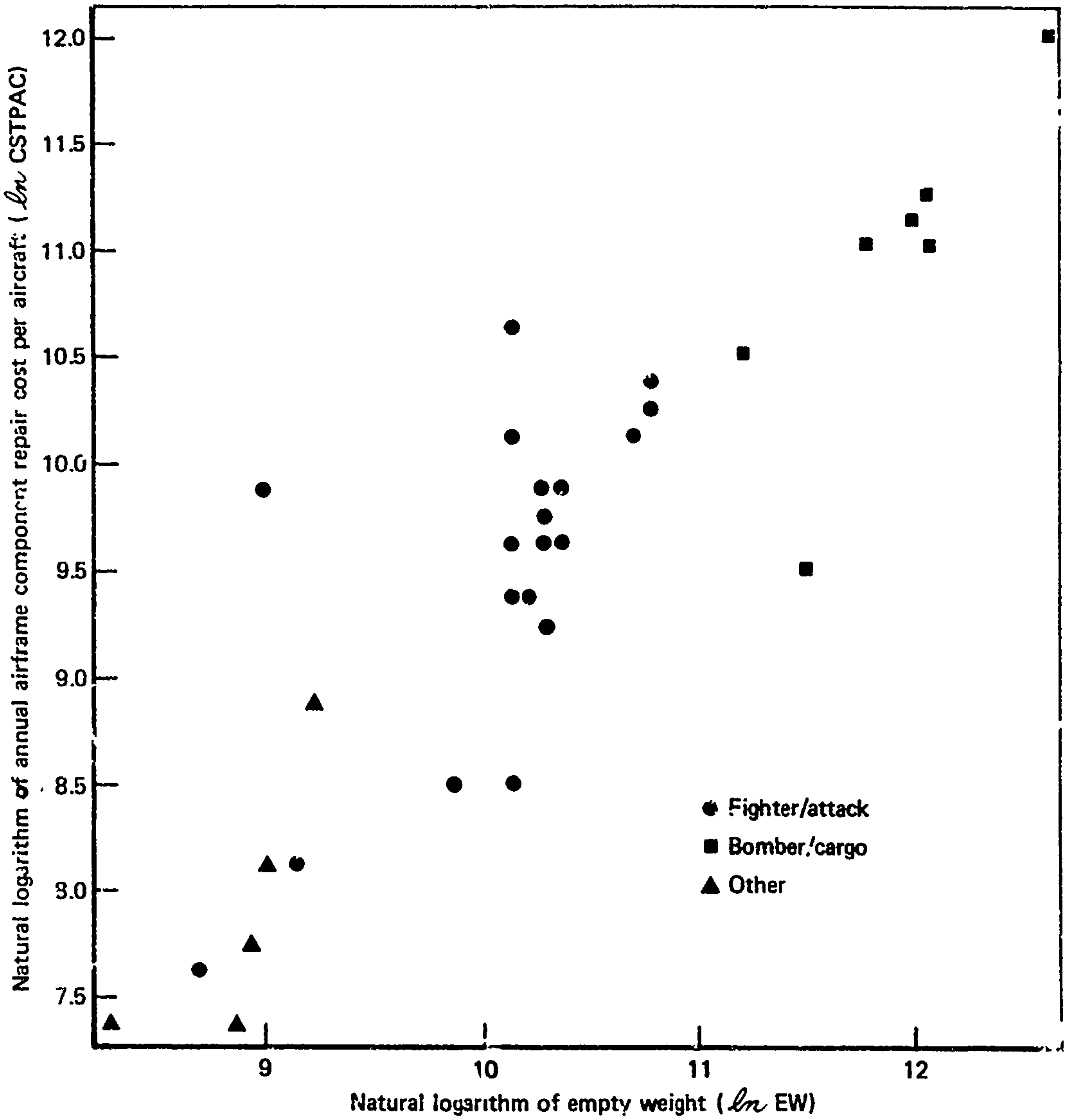

Fig. 5—Variation of annual airframe component repair cost with empty weight

Thus, as was the case with airframe rework, certain parts of the analysis were repeated with subsamples of fighter/attack and bomber/cargo aircraft. Additionally, as was also the case with airframe rework, certain parts of the analysis were repeated with a subsample of one series of each aircraft model in order to evaluate the possible bias caused by the unequal series weighting. These "most representative series" aircraft are identified in Table 13.

Estimating Relationships

The structure of the airframe component repair analysis is identical to that used for the airframe rework analysis. Acceptable equations incorporating airframe size and technical variables were determined first, and then utilization and policy variables were added where they were significant.

Mnemonics used are:

ABDES = afterburner designator (1 = no afterburner, 2 = afterburner)
AFMFGC = airframe manufacturing cost (cumulative average for 100 airframes; 1978 dollars)
AFCCST = annual airframe component repair cost per aircraft (1978 dollars)
EW = empty weight (lbs)
SORPAC = average number of annual sorties per possessed aircraft

Total Sample. Estimating relationships incorporating variables significant at the 5 percent level are provided in Table 14. The equations are relatively good, although the standard error of estimate is somewhat higher than desirable.

Most Representative Series. Estimating relationships incorporating variables significant at the 5 percent level are provided in Table 15. Contrasting these equations to those developed for the total sample, we find there is very little difference.

Mission Samples. Estimating relationships incorporating variables significant at the 5 percent level are provided in Table 16. Contrasting these equations with those developed for the total sample,

Table 14

AIRFRAME COMPONENT REPAIR COST ESTIMATING RELATIONSHIPS: TOTAL SAMPLE

Equation	Statistics R^2	SEE	F	N
Size				
$AFCCST = 0.788\ EW^{0.967}$ (.000)	.78	.54	116	34
Technical, Performance				
$AFCCST = 19.0\ AFMFGC^{1.07}$ (.000)	.78	.44	81	25
Size/Technical, Performance				
None				
Size/Utilization				
$AFCCST = 0.394\ EW^{1.00}\ ABDES^{0.663}$ (.000) (.008)	.82	.50	72	34
Technical, Performance/Utilization				
$AFCCST = 0.808\ AFMFGC^{1.26}\ SORPAC^{0.383}$ (.000) (.024)	.81	.41	48	25
Size/Policy				
None				
Technical, Performance/Policy				
None				

Table 15

AIRFRAME COMPONENT REPAIR COST ESTIMATING RELATIONSHIPS: MOST REPRESENTATIVE SERIES

Equation	Statistics				Comments
	R^2	SEE	F	N	
Size					
AFCCST 0.327 $EW^{1.03}$ (.000)	0.88	0.48	126	19	Exponent magnitude
Technical, Performance					
AFCCST = 16.3 $AFMFGC^{1.10}$ (.000)	0.83	0.49	56	13	
Size/Technical, Performance					
None					
Size/Utilization					
None					
Technical, Performance/Utilization					
AFCCST = 0.678 $AFMFGC^{1.26}$ (.000) $SORPAC^{0.430}$ (.046)	0.88	0.44	36	13	
Size/Policy					
None					
Technical, Performance/Policy					
None					

Table 16

AIRFRAME COMPONENT REPAIR COST ESTIMATING RELATIONSHIPS: MISSION SUBSAMPLES

Equation	Statistics			
	R^2	SEE	F	N
Fighter/Attack Subsample				
Size				
$AFCCST = 0.894\ EW^{0.970}$ (.000)	0.48	0.58	17	20
Technical, Performance				
$AFCCST = 144\ AFMFGC^{0.748}$ (.003)	0.43	0.39	11	16
No other fighter/attack estimating relationships uncovered.				
Bomber/Cargo Subsample				
Si..				
$AFCCST = 0.603\ EW^{0.974}$ (.011)	0 61	0.51	9	8
Technical, Performance				
$AFCCST = 23.1\ AFMFGC^{1.03}$ (.007)	0.73	0.44	14	7
.o other bomber/cargo estimating relationships uncovered.				

we find that based on the standard error of estimate ther: is little difference. Furthermore, the empty weight exponent remains remarkably stable regardless of the sample selected. On the other hand, the airframe manufacturing cost exponent fluctuates considerably for the fighter/attack sample.

Excursion. The PDM designator, when utilized as a dummy variable, did not meet our 5 percent significance level criterion. An excursion was made in which the total sample was split according to PDM policy (see Table 13). Those aircraft which switched policy during the

1975-1977 time period were excluded. The results of this analysis are as follows:

	R^2	SEE	F	N	COMMENT
Aircraft Without PDM					
$AFCCST = 3.06\ AFMFGC^{1.30}$ (.000)	0.99	.10	499	8	
$AFCCST = 0.019\ EW^{1.32}$ (.000)	0.97	.22	308	11	Exponent magnitude
Aircraft With PDM					
$AFCCST = 81.2\ AFMFGC^{0.884}$ (.014)	0.40	.55	7	12	
$AFCCST = 65.3\ EW^{0.569}$ (.004)	0.51	.49	10	12	

As indicated, the estimating relationships for aircraft without a PDM program are quite good. However, one should be aware that the "without PDM" sample does not include any large bomber or cargo aircraft. Consequently, the "without PDM" estimating relationships should probably not be used for large bombers or cargo aircraft. This is particularly true for the equation containing empty weight because of the large exponent (1.32). The equations for aircraft with a PDM program are not nearly as attractive, but do not compare very unfavorably with estimating relationships derived for samples not differentiated by PDM policy.

Summary. Empty weight and airframe manufacturing cost both seem to do a reasonable job of explaining annual airframe component repair cost. Additionally, although sample stratification by mission type does not provide any significant benefit, the distinction between

aircraft with a PDM program and those without would seem to be important. For general usage, one of the following estimating relationships is suggested:

$$AFCCST = 0.788\ EW^{.967}$$

$$AFCCST = 19.0\ AFMFGC^{1.07}$$

ENGINE COMPONENT AND ACCESSORY REPAIR ANALYSIS

Engine component and accessory repair cost will be estimated on the basis of an annual cost per installed engine. Cost data to be used in the analyses are summarized in Table 17. Candidate explanatory variable values (the same as those used in the engine overhaul and repair analysis) may be found in App. D.

Data Base

The data base is initially limited to the same 17 engines used in the engine overhaul and repair analysis:

J33-A-35	J79-GE-15
J57-P-19W/29WA	J85-GE-5H
-21A/B	TF30-P-3
-43WB	-100
-59W	TF33-P-3
J60-P-3/3A	-7/7A
J65-W-5F	TF39-GE-1A
J69-T-25	TF41-A-1/1A
J75-P-17	

Additionally, an examination of Table 17 indicates that the J75 is at least an order of magnitude less expensive than any other engine on the list above. Further examination of the costs in a more disaggregated form strongly suggests an error in the raw data. The J65 is therefore deleted from the sample.

Table 17

ENGINE COMPONENT AND ACCESSORY REPAIR COST:
AVERAGES FOR 1975-1977

(Costs in 1978 dollars)

Engine	Installed Engine	Annual Engine Component Repair Cost ($/engine)	Engine	Installed Engine	Annual Engine Component Repair Cost ($/engine)
J-33-A-35	207	1,374	TF33-P-3	735	5,888
J-57-P-13A/B	87	8,168	-5	100	4
-19W/29WA	1018	11,066	-7/7A	1095	13,604
-21A/B	356	12,291	-9	103	10
-23B	65	7,795	TF34-GE-100	108	3,684
-43WB	1601	8,273	TF39-GE-1/1A	277	43,774
-55/55A	218	24,551	TF41-A-1/1A	354	24,783
-59W	2613	5,738	F100-PW-100	338	7,926
J60-P-3/3A	261	3,325	-23A	338	126
J65-W-5F	77	98	-23B	338	41
J69-T-25	1397	912	-23C	338	10
J75-P-17	199	38,486	-23F	338	3,923
-19/19W	194	25,730	-23G	338	12
J79-GE-15	2112	9,030	T56-A-7B	1596	5,747
-17/17A	1286	7,598	-[illegible]B	549	not incl.
J85-GE-5H	1831	1,550	-[illegible]5	542	not incl.
-13	23	7,209	G56-A-7B	1032	59
-17A	280	1,314	-[illegible]B	547	not incl.
-21	201	402	-15	1276	not incl.
TF30-P-3	313	27,198	T76-GE-10A	92	1,035
-7	116	27,745	-12A	90	1,011
-9	147	15,653			
-100	174	28,615			

Figure 7 is a plot of annual engine component and accessory repair cost as a function of the engine pressure term. Appendix E contains additional plots using other potential explanatory variables.

Estimating Relationships

Estimating relationships incorporating variables significant at the 5 percent level are provided in Table 18. Mnemonics used are as follows:

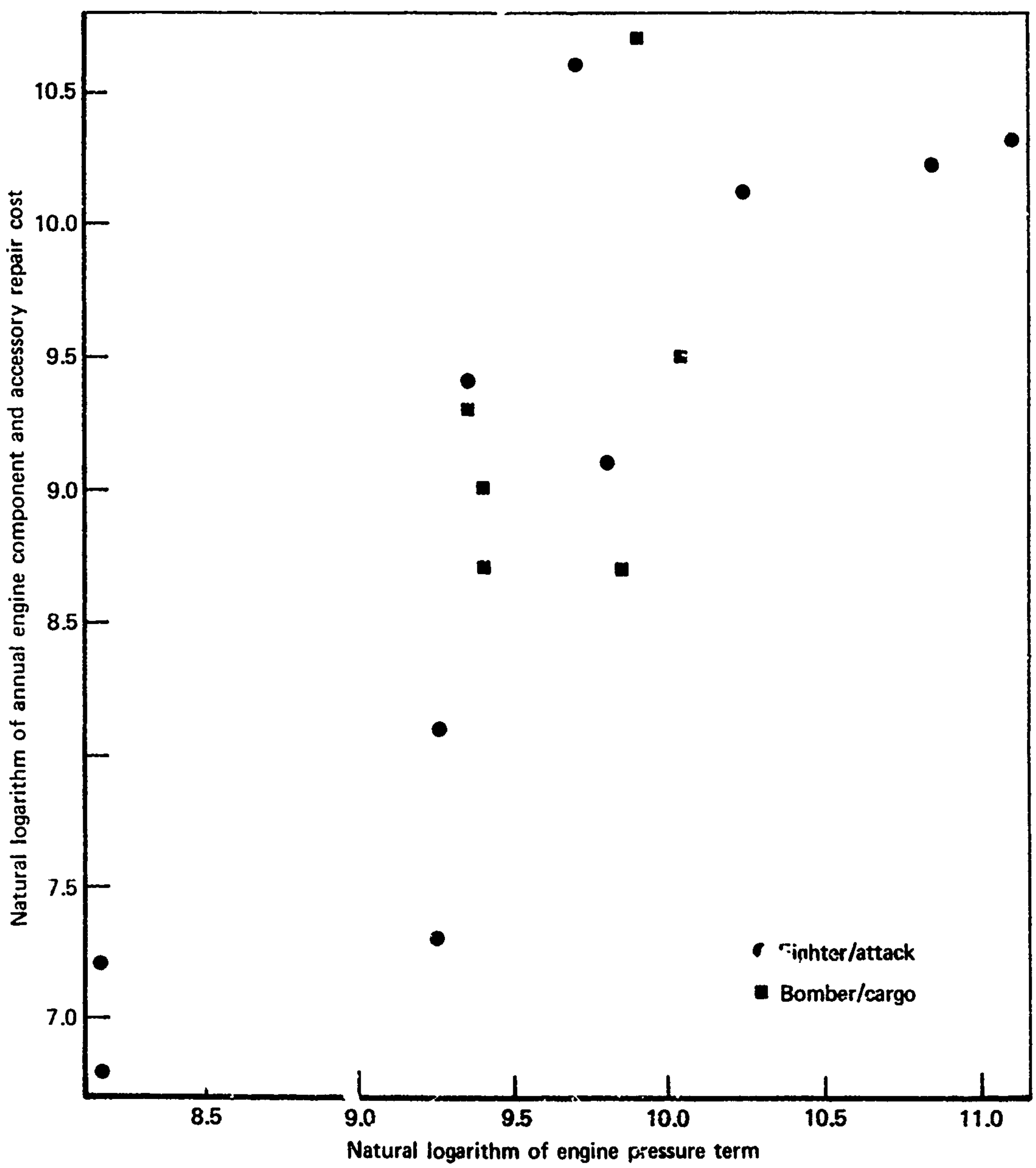

Fig. 7—Variation of annual engine component and accessory repair cost with engine pressure term

Table 18

ENGINE ANNUAL COMPONENT AND ACCESSORY REPAIR COST ESTIMATING RELATIONSHIPS

Equation	Statistics				Comments
	R^2	SEE	F	N	
Performance					
$ENGACC = (1.67 \times 10^{-22})\ TEMP^{7.75}$ (.001)	.48	.90	13	16	Exponent magnitude
$ENGACC = .086\ PRSTERM^{1.23}$ (.000)	.65	.73	26	16	Exponent magnitude
$ENGACC = 5920\ SFC^{-2.59}$ (.001)	.50	.88	14	16	Exponent magnitude
$ENGACC = .00367\ SELLPR^{1.14}$ (.000)	.79	.57	52	16	Exponent magnitude
Size					
$ENGACC = .605\ WT^{1.05}$ (.000)	.66	.73	27	16	
$ENGACC = .196\ MAXTH^{1.15}$ (.000)	.81	.54	61	16	Exponent magnitude
$ENGACC = .299\ MILTH^{1.15}$ (.000)	.74	.64	40	16	Exponent magnitude
Performance/Size					
$ENGACC = (4.58 \times 10^{-16})\ TEMP^{4.94}\ WT^{.825}$ (.002) (.000)	.83	.54	31	16	Exponent magnitude
$ENGACC = (4.69 \times 10^{-10})\ TEMP^{2.82}\ MAXTH^{.962}$ (.036) (.000)	.86	.49	39	16	Exponent magnitude
$ENGACC = (1.30 \times 10^{-11})\ TEMP^{3.37}\ MILTH^{.918}$ (.036) (.000)	.80	.58	26	16	Exponent magnitude
$ENGACC = .0265\ PRSTERM^{.778}\ WT^{.677}$ (.001) (.001)	.84	.52	34	16	
$ENGACC = 70.4\ PRSTERM^{.639}\ MILTH^{.771}$ (.008) (.001)	.84	.52	33	16	r (PRSTERM, MILTH) = .67
Performance/Application					
$ENGACC = (7.34 \times 10^{-21})\ TEMP^{7.58}\ SORTENG^{-.515}$	.58	.84	9	16	Exponent magnitude; sign of SORTENG
$ENGACC = .0311\ PRSTERM^{1.31}\ SINGDES^{1.13}$ (.000) (.034)	.73	.67	18	16	Exponent magnitude
$ENGACC = 6090\ SFC^{-2.92}\ RSVPCT^{.103}$ (.000) (.047)	.60	.82	10	16	Exponent magnitude
$ENGACC = .00238\ SELLPR^{1.16}\ SINGDES^{.791}$ (.000) (.050)	[illegible]	.53	32	16	Exponent magnitude
Size/Application					
$ENGACC = 6.68\ WT^{.903}\ TFDES^{.971}$ (.000) (.050)	.73	.68	17	16	
$ENGACC = .0186\ MILTH^{1.39}\ MISSDES^{1.24}$ (.000) (.009)	.83	.53	33	16	Exponent magnitude

ENGACC = annual engine component and accessory repair cost per engine ($)
MAXTH = maximum thrust (lbs)
MILTH = military thrust (lbs)
PRSTERM = engine pressure term (lbs/ft^2)
RSVPCT = percentage of engine operating hours flown by Guard/Reserve personnel
SELLPR = engine selling price (unit 1000 in 1978 dollars)
SINGDES = single engine designator (multiple = 1; single = 2)
SORTENG = annual engine sortie rate (sorties/year)
TEMP = turbine inlet temperature (°R)
TFDES = turbofan designator (1 = no; 2 = yes)
WT = engine weight (lbs)

As was the case with the engine overhaul and repair estimating relationships, the component and accessory repair CERs also exhibit some fairly large exponents. However, the size and performance CERs are, as a group, the best of the engine depot-level estimating relationships documented in this report. As to the choice of which component repair equation to actually use, consistency with the overhaul and repair equations would suggest the following estimating relationship:

$$ENGACC = .0265 \quad PRSTERM^{.778} \; WT^{.677}$$

AVIONICS COMPONENT REPAIR COST

Avionics component repair cost will be estimated on the basis of an annual cost per aircraft. Cost data to be used in the analysis are summarized in Table 19. Candidate explanatory variable values may be found in App. D.

Data Base

The A-10A, F-15A, and TF-15A were excluded from the analysis because they were phasing into the inventory during the 1975-1977 time period and consequently are of dubious value to a study oriented to the costs of mature systems. The 32 remaining avionics suites were included in the analysis according to the availability of input data. Suite characteristics proved difficult to obtain because of

Table 19

AVIONICS COMPONENT REPAIR COST:
AVERAGES FOR 1975-1977

(Costs in 1978 dollars)

MDS	Inventory	Annual Fleet Flying Hours	Annual Avionics Repair Cost per Aircraft
A-7D	365	94,556	19,749
A-10A	29	13,270	5,454
A-37	113	28,537	4,218
B-52D	89	31,752	99,897
B-52G	162	69,240	116,793
B-52H	89	38,182	160,808
C-5A	65	44,430	289,866
C-130E	281	170,188	40,859
C-141A	248	277,727	83,207
F-4C	270	62,261	38,288
F-4D	444	106,309	31,755
F-4E	594	152,329	29,306
F-5B	9	3,260	28,895
F-5E	51	12,121	16,717
F-15A	83	18,544	8,289
F-101B	112	26,779	21,360
F-105B	34	8,015	31,065
F-105D	99	21,645	32,777
F-105F	19	3,921	50,660
F-105G	42	8,818	42,923
F-106A	175	53,969	69,226
F-106B	37	11,532	129,032
F-111A	93	17,602	97,902
F-111D	84	16,837	176,154
F-111E	79	20,010	125,397
F-111F	85	21,609	117,030
T-33A	226	64,234	6,262
T-37B	634	291,079	4,595
T-38A	872	350,926	7,946
T-39A	109	101,996	24,436
FB-111A	66	17,520	136,303
KC-135A	653	212,491	23,585
OV-10A	87	29,205	13,010
RF-4C	346	91,975	51,338
TF-15A	22	5,436	15,711

the number of black boxes and contractors involved with each aircraft and because suites change constantly, not only between aircraft of a given series but also on a given aircraft (tail number). Additionally, since most avionics contracts are firm fixed price, contractors are not required to divulge costs. However, the data base we have been able to put together covers a wide range of characteristics:

Characteristics	Range	Number of Points
Suite weight (lbs)	230-6200	16
Number of black boxes	5-34	31
Number of functions	2-6	31
Suite procurement cost #1 ($)[a]	26,000-3,705,000	29
Suite procurement cost #2 ($)[b]	220,000-10,410,000	16
Mean time between OFM demands (FH)	0.75-13.72	16

[a]Procurement cost of avionics suite at unit 100 in 1978 dollars (based on contract data).

[b]Sum of D041 item (NSN) procurement costs for all items in avionics suite (average of 1975-1977 entries).

Figure 8 is a plot of the annual avionics component repair cost as a function of the suite procurement cost. Appendix E presents additional plots using other potential explanatory variables.

Estimating Relationships

Estimating relationships incorporating variables significant at the 5 percent level are provided in Table 20. Mnemonics used are as follows:

AVCST = annual avionics repair cost per aircraft ($)
AVWT = avionics suite weight (lbs)
AWXDV = all-weather capability dummy variable (no = 1; yes = 2)
BLBOX = number of black boxes in suite (#)
FHRATE = annual flying hour rate (hours)
FUNC = number of electronics functions performed by aircraft avionics suite (#)
MISSDV = mission dummy variable (1 = noncombat aircraft; 2 = combat aircraft)

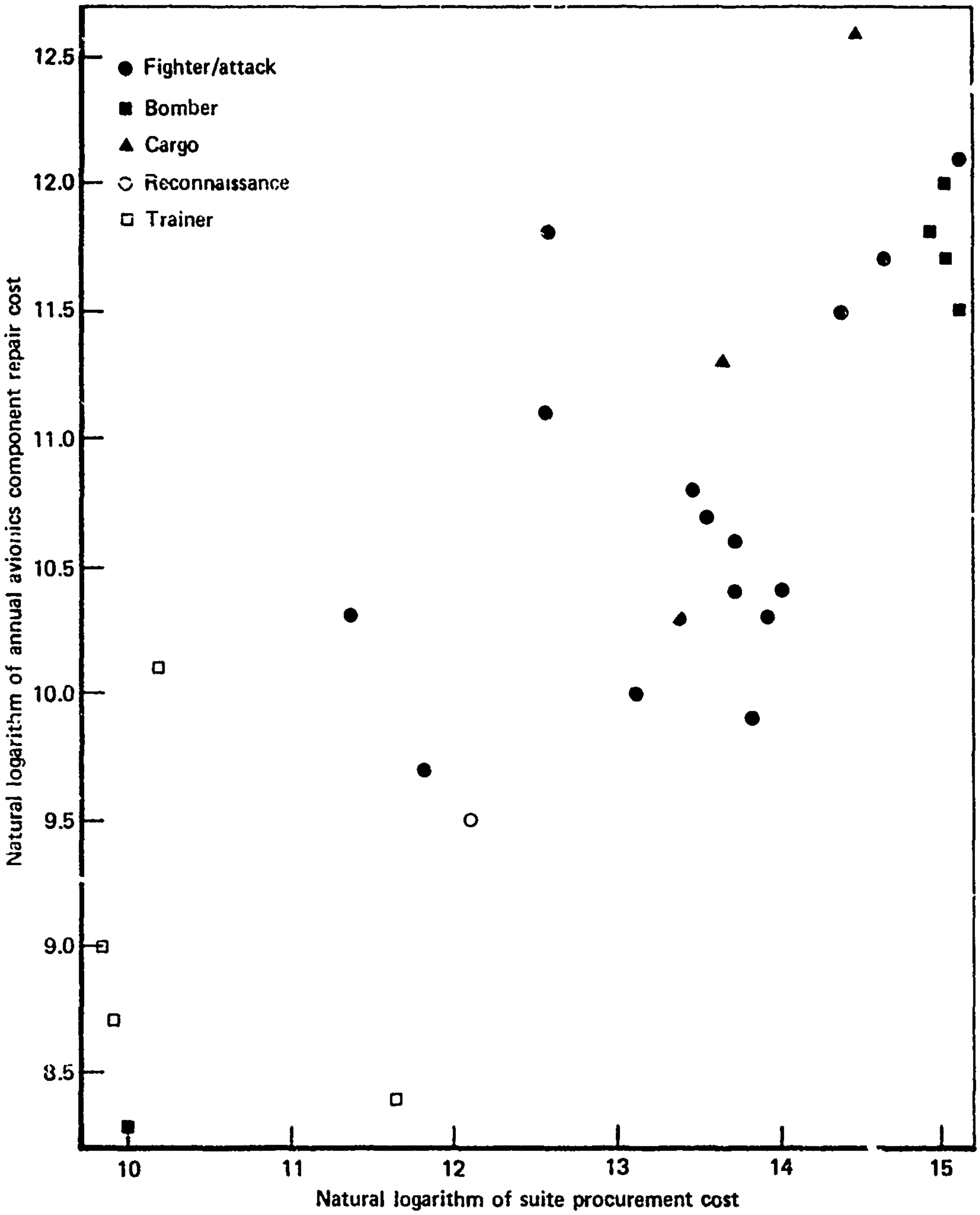

Fig. 8—Variation of annual avionics component repair cost with suite procurement cost

Table 20

AVIONICS COMPONENT REPAIR COST ESTIMATING RELATIONSHIPS

Equation	Statistics				Comments
	R^2	SEE	F	N	
$AVCST = 22.2\ AVWT^{1.09}$ (.000)	.65	.69	26	16	
Performance, Complexity					
$AVCST = 918\ BLBOX^{1.49}$ (.000)	.50	.78	29	31	Exponent magnitude
$AVCST = 4080\ FUNC^{2.15}$ (.000)	.49	.79	28	31	Exponent magnitude
$AVCST = 34.5\ SUITE1^{.557}$ (.000)	.66	.68	51	29	
$AVCST = .415\ SUITE2^{.811}$ (.000)	.79	.54	54	16	
$AVCST = 136000\ MTBD^{-1.01}$ (.000)	.56	.79	18	16	
$AVCST = 14000\ AWXDV^{2.61}$ (.000)	.53	.75	34	32	Exponent magnitude
Size/Performance, Complexity					
$AVCST = 17.9\ AVWT^{.742}\ BLBOX^{.967}$ (.006) (.030)	.74	.62	18	16	r (AVWT, BLBOX) = .66
Size/Application					
$AVCST = 65.5\ AVWT^{1.05}\ MISSDV^{-1.46}$ (.000) (.023)	.75	.61	19	16	Exponent sign
Performance, Complexity/Mission Descriptors					
$AVCST = 527\ BLBOX^{1.50}\ MISSDV^{.959}$ (.000) (.018)	.57	.73	19	31	Exponent magnitude
$AVCST = 2040\ BLBOX^{.858}\ AWXDV^{1.65}$ (.005) (.002)	.63	.68	24	31	Exponent magnitude
$AVCST = .074\ SUITE2^{.958}\ MISSDV^{-.937}$ (.000) (.035)	.84	.49	34	16	Exponent sign on MISSDV
Performance, Complexity/Application					
$AVCST = 34200\ BLBOX^{1.12}\ SORTRATE^{-5.36}$ (.001) (.036)	.56	.75	17	31	Exponent sign
$AVCST = .485\ SUITE1^{.593}\ FHRATE^{.654}$ (.000) (.013)	.72	.63	33	29	
$AVCST = .00455\ SUITE2^{.858}\ FHRATE^{.650}$ (.000) (.012)	.86	.46	41	16	
$AVCST = 281\ MTBD^{-1.23}\ FHRATE^{1.07}$ (.000) (.000)	.72	.65	17	16	Exponent magnitude

MTBD = mean time between OFM demands (hours)
SORTRATE = annual sortie rate (sorties)
SUITE 1 = procurement cost of avionics suite at unit 100 (1978 dollars)
SUITE 2 = sum of D041 item (NSN) procurement costs for all items in avionics suite ($)

Several of the estimating relationships have a familiar problem--exponent magnitude. Others have exponents with counterintuitive signs. For example, the sign of the mission dummy variable in the AVWT/MISSDV and SUITE2/MISSDV estimating relationships is negative, indicating that the cost of avionics component repair for combat aircraft is less than for noncombat aircraft. Equally interesting is the fact that the mission dummy variable has a positive exponent in the BLBOX/MISSDV estimating relationship. This flip-flopping of the exponent sign suggests a relatively unstable variable.

On the positive side, the CERs utilizing suite procurement cost appear quite acceptable. The SUITE2 variable actually does better from a statistical standpoint than does the SUITE1 variable. Intuitively, one might expect this, since SUITE2 is based on the current cost of suite items (including costs of items incorporated as the result of modifications) while SUITE1 is based on quantity-normalized historical data. Table D.3 indicates significant differences between the two procurement cost values, but the correlation between the two is relatively high (r = .90). If one should want to use an estimating relationship utilizing suite procurement cost, then one of the following is recommended:

$$AVCST = .415\ SUITE2^{.811}$$

$$AVCST = .00455\ SUITE2^{.858}\ FHRATE^{.650}$$

The SUITE2 value for proposed aircraft can be approximated by the estimated avionics suite cost at the projected production. Attempting to estimate mature aircraft SUITE2 costs would be an exercise in futility, because of modifications unknown during the early stages of design.

TOTAL COST EQUATIONS

The equations developed for the different categories of depot maintenance activity have one common feature: They have poorer statistics (e.g., higher standard errors of estimate) than we would like. An alternative approach was therefore considered: the use of subsystem parameters to estimate the total cost of all types of depot maintenance activity. Although this does not give insight into the relative costs of the individual categories, sensitivity to subsystem characteristics can be retained.

The cost and explanatory variable data used for the individual categories gave full coverage of the data needed for 19 weapon systems. The total cost for each system was evaluated and analyzed as a cost per possessed aircraft. These values are presented in Table 21.*

The objective of the analysis was to develop equations that include variables describing the airframe, engine, and avionics subsystems as well as the aircraft utilization. Table 22 presents the best results obtained from this data. Mnemonics used are:

Variable	Subsystem	Definition
ACFFD	Avionics	Aircraft first flight date (months since January 1943)
EW	Airframe	Empty weight (lbs)
INV	System	Inventory size, the number of possessed aircraft
MILTH	Engine	Military thrust (lbs)
NENG	System	Number of installed engines per airframe
PRSTERM	Engine	Engine pressure term (psf)
SELLPR	Engine	Selling price for 1000th engine (1978 dollars)
SFC	Engine	Specific fuel consumption (lbs/hr/lb)
SUITE1	Avionics	Procurement cost of avionics suite at unit 100 (1978 dollars)
TCSTPAC	System	Annual depot maintenance cost per aircraft (1978 dollars)
WT	Engine	Engine dry weight (lbs)

*Appendix C presents a comparison of these costs with corresponding costs taken from output for 1977 from the Air Force's Operating and Support Cost Analysis Report (OSCAR).

Table 21

AVERAGE DEPOT MAINTENANCE COST: 1975-1977

(In $ thousand 1978)

MDS	Annual Cost per Aircraft
A-7D	145
B-52D	320
B-52G	535
B-52H	551
C-5A	1109
C-141A	317
F-4C	146
F-4D	129
F-106A	201
F-106B	279
F-111A	229
F-111E	280
F-111F	309
T-33A	15
T-37B	11
T-38A	20
T-39A	53
KC-135	105
RF-4C	153

Table 22

TOTAL SYSTEM DEPOT-LEVEL COST ESTIMATING RELATIONSHIPS

Equation	Statistics R^2	SEE	F	N
1. $TCSTPAC = 7.49\ \underset{(.008)}{INV^{-0.315}}\ \underset{(.000)}{EW^{0.664}}\ \underset{(.001)}{PRSTERM^{0.475}}$	.93	.37	62	19
2. $TCSTPAC = 4.66\ \underset{(.005)}{INV^{-0.332}}\ \underset{(.000)}{EW^{0.573}}\ \underset{(.001)}{SELLPR^{0.467}}$	.93	.36	64	19
3. $TCSTPAC = 8.51\ \underset{(.001)}{INV^{-0.408}}\ \underset{(.000)}{EW^{0.698}}\ \underset{(.001)}{ACFFD^{0.862}}$	.93	.37	62	19
4. $TCSTPAC = 10200\ \underset{(.008)}{INV^{-0.434}}\ \underset{(.006)}{SFC^{-1.45}}\ \underset{(.001)}{SUITE1^{0.348}}$	.90	.47	38	17
5. $TCSTPAC = 5.57\ \underset{(.000)}{INV^{-0.402}}\ \underset{(.000)}{ACFFD^{0.972}}\ \underset{(.000)}{WT^{0.836}}\ \underset{(.000)}{NENG^{0.566}}$	.96	.28	85	19
6. $TCSTPAC = 2.51\ \underset{(.000)}{INV^{-0.354}}\ \underset{(.000)}{ACFFD^{0.691}}\ \underset{(.000)}{MILTH^{0.953}}\ \underset{(.000)}{NENG^{0.522}}$	.97	.23	130	19

As shown in Table 22, no estimating relationships incorporating one airframe, one engine, one avionics, and one utilization variable could be found. The parameters associated with each subsystem tend to be correlated with those of the other systems. The best equations, as shown in the table, include parameters representing, at most, two of the three subsystems. The statistics of these equations are better than those of the equations for the individual categories. The one variable included in all these equations is inventory size, INV. Since its exponent is negative, we have evidence of a fixed cost being associated with depot maintenance. Figure 9 illustrates this effect.

The last two equations in the table have the best statistics of any generated during this study:

$$TCSTPAC = 5.57\ INV^{-.402}\ ACFFD^{.972}\ WT^{.836}\ NENG^{.566}$$

$$TCSTPAC = 2.51\ INV^{-.354}\ ACFFD^{.691}\ MILTH^{.953}\ NENG^{.522}$$

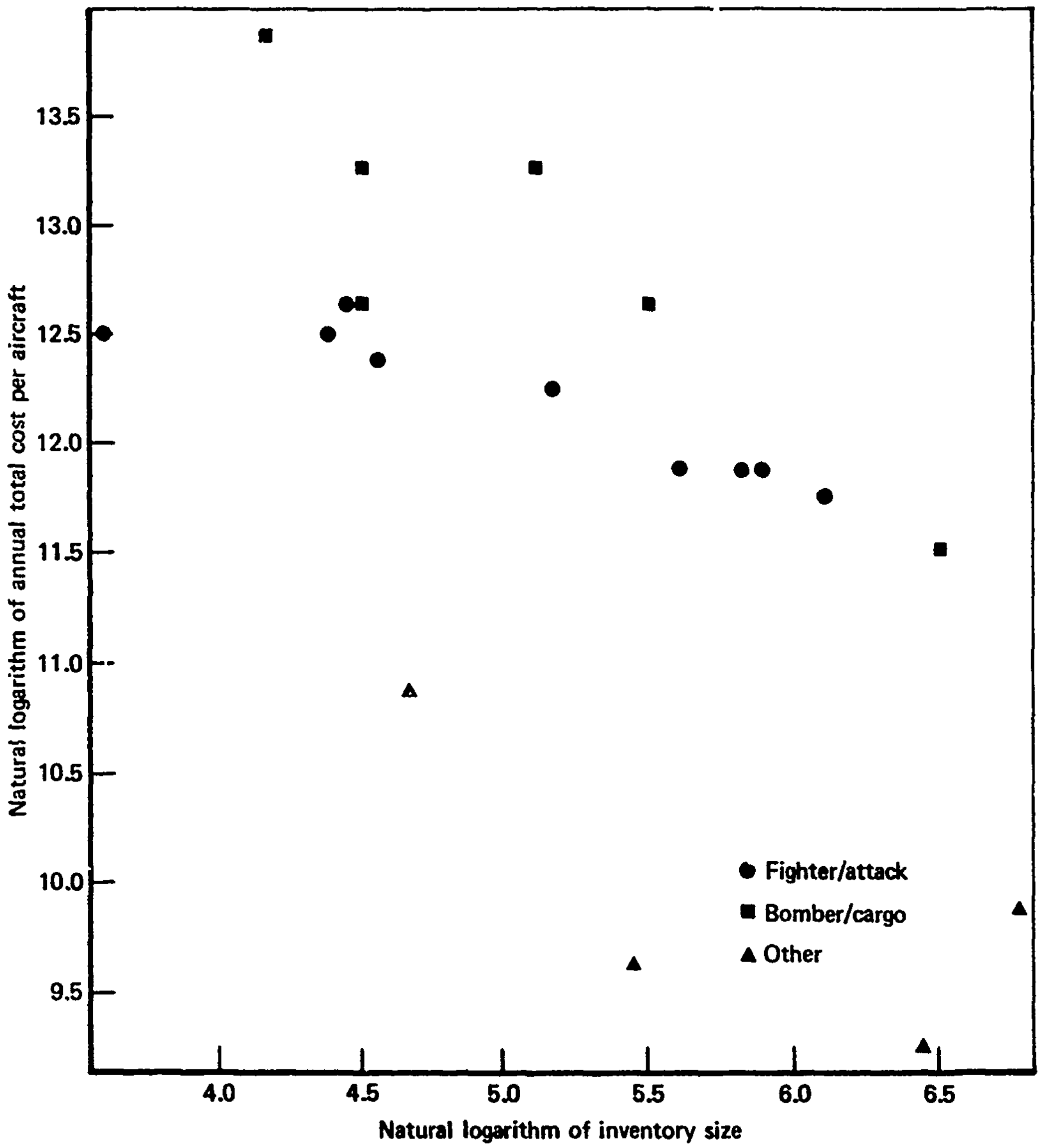

Fig. 9—Variation of total cost per aircraft with inventory size

V. SUMMARY OF RESULTS AND CONCLUSIONS

The previous section presented a large number of worthwhile estimating relationships. We now consider the overall implications of the study results. A summary of the significant variables for airframe, engine, and avionics maintenance is followed by an example of some applications of some subsystem- and system-level estimating relationships. This section closes with suggestions for possible extensions of this research during future studies.

PRINCIPAL FINDINGS

Several equations, instead of only one, were generated for each cost category. Thus, rather than having only a single preferred equation in each category, one has an opportunity to consider a number of equations and select the one most likely to capture the effects that are critical to a particular situation. There is also a potential for deriving an improved understanding of the nature of depot maintenance through an examination of the full set of equations. As a start, the following paragraphs summarize the results for each maintenance category.

Airframes

The variables found to be significantly* related to at least one of the relevant measures of cost (at the 5 percent level in at least one estimating relationship) include fleet flying hours, inventory, age, maximum load factor, empty weight, maximum takeoff weight, airframe manufacturing cost, the afterburner designator, sortie rate, and PDM policy. In some cases separate equations were developed for fighter/attack and bomber/cargo aircraft, reflecting the influence of mission type. Factors found to be not significantly related to airframe rework cost are the operating climate, and speed and altitude

*Subject to the satisfaction of other statistical criteria (e.g., exponent size, collinearity) and the ground rule that utilization and policy variables would be useful only as a supplement to size and performance variables.

measures. A few interesting parameters were not tested because data were not available in sufficient quantity. These are landing rate, material composition, contractor identity, PDM interval, and the use of dock crews or specialists to perform PDMs.

Results for airframe component repair are similar. The two most useful variables are airframe manufacturing cost and aircraft empty weight. They are about equally useful, which is not surprising since they are highly correlated.

Table 23 summarizes these results.

Engines

At least one significant variable was found in each of the three variable classes (i.e., technical, size, or application variables) for each of the four depot-level engine cost categories: average time between overhaul (ATBO), average cost per overhaul, annual cost to repair, and annual component and accessory repair cost. Table 24 summarizes those explanatory variables which were found statistically significant* at the 5 percent level in one or more estimating relationships.

As indicated, several variables show up consistently in each cost category. Unfortunately, most of the estimating relationships in which these variables appear are of relatively poor statistical quality and have unusually large exponents, thereby creating serious reservations about their utility.

Avionics

For annual avionics component repair cost, 14 explanatory variables were grouped according to whether they describe the size, performance/complexity, or application aspects of avionics suites. At least one significant variable was found in each of these three classes. Table 25 summarizes those explanatory variables which were found

*Subject to the satisfaction of other statistical criteria (e.g., exponent size, collinearity) and the ground rule that application variables would be useful only as supplements to size and performance variables.

Table 23

SUMMARY OF RESULTS FOR AIRFRAME VARIABLES

	Results				
	Rework[a]				
Explanatory Variable	Total Cost	Cost per Aircraft	Cost per Visit	Production Quantity	Component Repair
SIZE					
Empty weight	X[b]	X	X		X
Maximum takeoff weight	X	X	X		X
TECHNICAL/ PERFORMANCE					
Speed					
Altitude					
Dynamic pressure					
Load factor	X	X	X		X
Airframe cost	X	X	X		X
Afterburner	X		X		
Mission	X	X	X		X
UTILIZATION					
Flying hours	X			X	X
Inventory	X			X	X
Age	X		X		X
Sorties	X			X	X
Reserve percent			X		X
Climate				X	
POLICY					
Organic maintenance percent			X	X	X
PDM policy	X	X			X

[a]See App. F for results for Total Cost, Cost per Visit, and Production Quantity.

[b]X = Significant at 5 percent level in one or more relationships.

Table 24

SUMMARY OF RESULTS FOR ENGINE VARIABLES

Explanatory Variable	ATBO	Cost per Overhaul	Annual Cost per Repair	Annual Component and Accessory Repair Cost
TECHNICAL/PERFORMANCE				
Turbine inlet temp.	X	X	X	X
Thrust-to-weight ratio				
Pressure term (psf)	X	X	X	X
Specific fuel consumption		X	X	X
Maximum mach number				
Removal rate	X	NT		
Selling price	X	X	X	X
SIZE				
Weight	NT	X	X	X
Maximum thrust	NT	X	X	X
Military thrust	NT	X	X	X
APPLICATION				
Mission designator	X	NT	X	X
Fighter/attack designator		NT		
Single engine designator	X	NT	X	X
Reserve/Guard fraction	X	NT	X	X
MISCELLANEOUS				
Turbofan designator	NT			X
Manufacturer designator				
Type maintenance indicator	NT	X	X	

Notes:

NT = Not tested for cost category because a priori rationale could not be established.

X = Significant at 5 percent level in one or more relationships.

Table 25

SUMMARY OF RESULTS FOR AVIONICS VARIABLES

Explanatory Variable	Significant at 5% Level in One or More Cases (Yes/No)
SIZE	
Suite weight	Yes
PERFORMANCE, COMPLEXITY	
Aircraft first flight date	No
Number of black boxes	Yes
Number of functions	Yes
Suite procurement cost #1	Yes
Suite procurement cost #2	Yes
Mean time between suite demands	Yes
Combat/noncombat designator	Yes
All-weather designator	Yes
Mission group designator	No
APPLICATION	
Annual aircraft flying hours	Yes
Annual aircraft sorties	No
Percentage of unique items ($ value)	No
Percentage of unique items (item count)	No

statistically significant* at the 5 percent level in one or more estimating relationships.

As indicated, over 60 percent of the variables tested were found significant in one or more estimating relationships. Unfortunately, as was the case with the engine CERs, most of the estimating relationships in which these variables appear are of relatively poor statistical quality and have unusually large exponents. Suite procurement cost and the annual flying hour rate appear, at this time, to be the most credible avionics explanatory variables.

*Same qualification as for engine CERs.

APPLICATION OF ESTIMATING RELATIONSHIPS

The equations in Sec. IV provide a number of useful approaches to estimating the total depot maintenance cost of a new aircraft. The following set of equations, first presented in Sec. I, should be applicable to a wide range of situations:

Airframe Rework	$AFRWKC = 183.2\ EW^{0.344}\ PDM^{3.224}$
Engine Overhaul/ Repair	$AVGCOH = 0.598\ PRSTERM^{0.793}\ WT^{0.390}$
	$ANNCTR = 2.72\times10^{-8}\ PRSTERM^{1.49}\ WT^{1.24}$
Airframe Components	$AFCCST = 0.7877\ EW^{0.9668}$
Engine Components/ Accessories	$ENGACC = 0.0265\ PRSTERM^{0.778}\ WT^{0.677}$
Avionics Components	$AVCST = 0.00455\ SUITE2^{0.858}\ FHRATE^{0.650}$

The mnemonics used in these equations are as follows:

AFCCST = annual airframe component repair cost per aircraft (1978 dollars)
AFRWKC = annual airframe rework cost per aircraft (1978 dollars)
ANNCTR = annual engine cost to repair (1978 dollars)
AVCST = annual avionics repair cost per aircraft (1978 dollars)
AVGCOH = average engine overhaul cost (1978 dollars)
ENGACC = annual engine accessory and component cost per aircraft (1978 dollars)
EW = aircraft empty weight (lbs)
FHRATE = annual MDS flying hour rate
PDM = PDM policy designator
PRSTERM = engine pressure term (psf)
SUITE2 = avionics suite procurement cost
WT = engine weight (lbs)

Table 26 shows the results obtained when these subsystem equations are applied to five recent aircraft in the data base. The A-7D, B-52H, C-141A, and F-111F are used here because they are the newest

attack, bomber, cargo, and fighter aircraft that are present in the data base in considerable numbers. The F-4D is included because it is somewhat more typical of fighters in general than is the considerably heavier F-111F. Also shown are the results of applying to these same aircraft the total cost per aircraft equations listed in Table 22. At the bottom of Table 26 is shown a mean absolute relative deviation computed for each equation from the five results shown in the table. This provides a measure of how well each equation would predict the depot maintenance costs of these recent aircraft, the aircraft most likely (of any in our data base) to be similar to the aircraft with which cost estimators will be dealing in the future.

Each of the two estimating approaches is valid and useful. Some of the total cost equations have lower deviations than the results derived from this set of subsystem equations. On the other hand, the

Table 26

ALTERNATIVE TOTAL COST ESTIMATES PER AIRCRAFT
(In $ thousand 1978)

MDS	Data Base	Subsystem Equation	Total Cost Equation[a]					
			1	2	3	4	5	6
A-7D	145	109	108	97	108	182	116	150
B-52H	551	621	589	479	643	705	560	649
C-141A	317	352	398	295	317	267	255	328
F-4D	129	167	105	125	115	118	157	139
F-111F	309	328	455	379	393	417	413	388
Mean absolute relative deviation			0.25	0.16	0.16	0.23	0.19	0.12

[a]See Table 22.

subsystem equations provide more information about the makeup of the total cost and about subsystem-level cost drivers. There is no one approach, one estimating equation, or set of equations, that is best for all uses. The approach preferred in a given case will depend upon the objectives of the cost estimator in that particular case.

POSSIBLE IMPROVEMENTS

Several issues that arose during this study could not be dealt with completely. Some of these are important enough that they should be part of studies of depot maintenance costs that might be undertaken in the future. Some involve data limitations; others relate to the analysis itself.

Data Issues

Data limitations in this study prevented a full analysis of the effects of system age on the costs of airframe rework and engine overhaul. Such an analysis would have to be based on data covering at least several (and perhaps many) years of the operating life of a significant number of systems. There seems to be no standard source of data for either airframes or engines that could provide all of the data needed. The G098 system maintained at the San Antonio Air Logistics Center may have useful data for some airframes, starting in 1971; but a recent status report indicates that all of the data files in G098 are not complete for all years. A good analysis of the effects of age might hinge on a data base that could be assembled from bits and pieces of data collected from a number of standard and nonstandard data sources.

Use of WSCRS data has led to a data base that could not be quickly regenerated in the future if it were desirable to repeat the analysis with data from a later time period. The WSCRS programs have been modified in a number of ways since they were used to develop the raw data for this research. Some of the modifications were needed to accommodate changes in data elements that occurred as part of the changes in 1977 to a unified depot accounting system. The cost

elements now used in reporting depot maintenance data are more detailed than those available to Rand for the 1975-1977 time period. This provides new opportunities to learn more about the nature of depot costs, but it will be necessary in future work to use somewhat different processing steps. A good time to update this analysis might be after WSCRS has become an official Air Force data system. Changes in format and processing steps may occur less frequently in an official data processing system than in a set of programs with no official status.

Additional research could be done with the data collected for this project. The basic H036 data are especially valuable because they contain some information that was not included in the WSCRS files. For example, data identifying individual facilities could be very useful in studies of maintenance concepts or investigations of indirect costs or the relationships between the composition (and cost) of the labor force and the nature of the work performed.

The use of dock crews or functional specialists for PDMs is a policy that might be examined using H036 data. PDM costs could be accumulated by facility. If it were known which facilities use dock crews and which use specialists, the costs of PDMs for the two policies could be compared.

Identification of facilities would also make it possible to identify the relative cost of organic and contract maintenance more accurately than was possible in this research, which examined this issue only in a limited way because of various limitations. A more thorough analysis would need both cost and production quantity data by type of facility. These data are available from H036.

Having cost data by facility for similar types of work would be necessary in a study of the factors that determine the values of direct and indirect cost rates. Do skill levels or experience levels vary enough from one facility to another to result in differences in average direct labor rates? Do staffing differences between facilities result in different rates for operations overhead or general and administrative costs? Answering these and similar

questions would depend partly on having cost and quantity data by facility.

Analysis Issues

Analysis of the cost of avionics component repair would probably be more enlightening if conducted for individual subsystems or functions rather than for an entire avionics suite. The results of the analysis might not be useful at DSARC II, because data on subsystems are not available at that point. The improved understanding of avionics repair cost would likely be worth the effort, though, if only through its indirect influence on future decisions. A better understanding of what drives avionics repair cost would both help in decisionmaking and point out appropriate research topics for future needs.

A major consideration in the application of our results is the significant technology changes taking place today in aircraft design. This issue could not be addressed fully within this study, but it should be considered by potential users of these equations. New technology shows up in new materials and design practices that are introduced either to meet high performance requirements or to reduce maintenance demands. Airframes are being designed with increased reliance on composite materials, which have repair requirements considerably different from those of conventional materials. Some airframes are being designed with the expectation that they will not be subject to a regular program of airframe rework. The trend in engine design is toward modularity, which allows individual modules to be sent to the depot instead of an entire engine. Avionics systems are making increased use of digital computers and built-in test equipment. Many people expect the net result of changes such as these to be a sizable reduction in the amount of depot maintenance required for future weapon systems. To the extent that such reductions are realized, the depot maintenance costs of future aircraft may be lower than our equations will predict.

One way to start to address this question analytically would be through an examination of outliers, that is, data points that have magnitudes for one or more variables that are considerably different from those of other points in the data base. Quantitative techniques are available that can use objective methods to identify outliers. These techniques could perhaps identify variables that should be investigated in order to identify and understand the fundamental differences between the newest aircraft and the older aircraft that make up the major part of our data base. This should be an area of investigation in any future work with these data.

Appendix A
DEFINITIONS OF TERMS AND VARIABLES

COMPONENT REPAIR CATEGORIES

Five categories of components were identified for the purpose of processing cost data by category: airframe components, engine accessories and components, avionics components, armament components, and support equipment components. Data for each category were identified through the use of a Federal Stock Class (FSC) or Group and either a Work Breakdown Structure Code or Group Code. The contents of the categories are listed in Tables A.1 through A.5. Work Breakdown Structure Codes and Group Codes are listed elsewhere in this appendix. FSCs are defined in Cataloging Handbook H2-1, Federal Supply Classification, Part 1, Groups and Classes.

COST ELEMENTS

The cost of depot maintenance is the sum of the following individual cost elements.

- "Direct civilian labor cost" is the cost of civilian labor hours that are associated with a specific maintenance objective. Included are civilian pay, the cost of leave time (annual leave, sick leave, etc.), and government contributions to employee benefit programs.
- "Direct military labor cost" is the cost of military labor hours that are associated with a specific maintenance objective. The hourly rate is derived from annual composite rates furnished in DoD 7220.9-H, Accounting Guidance Handbook. These rates include basic pay, allowances, and certain government expenses such as Social Security taxes and reenlistment bonuses.

- "Other direct material cost" is the cost of material that is specifically required to carry out an authorized maintenance task and that loses its identity as a result of the maintenance task, either by becoming part of the item being repaired or by being consumed. This is the cost of direct material "other" than repairable components that are exchanged for serviceable items during the maintenance task. The cost of repairing these exchangeable components is potentially distributed throughout all seven cost elements.
- There are two contributions to "other direct costs": purchased services and travel. When a depot maintenance activity contracts out work incidental to maintenance that it is performing, the work done under that contract is considered a purchased service. The organization performing the purchased service may be either a government activity or a commercial firm. Travel and per diem expenses are direct costs when incurred in connection with work that will be charged as direct labor.
- There are also two elements of indirect costs--costs not charged direct to job orders. "General and administrative costs" are the expenses of organizational units that do not perform direct maintenance tasks. The term "Other Direct Costs" applies to the overhead expenses of direct maintenance units.
- When a complete maintenance task is carried out for the Air Force by a commercial firm or by another military service, the cost of the task falls into the cost element labeled "contracted out depot maintenance cost."

Table A.1

DEFINITION OF AIRFRAME COMPONENTS

FSC	WBS Code	Group Code	FSC	WBS Code	Group Code
1377	not xx6	not SU	42xx	not xx6	not SU
15xx	" "	" "	45xx	" "	" "
1610	" "	" "	47xx	" "	" "
1615	" "	" "	53xx	" "	" "
1620	" "	" "	63xx	" "	" "
1630	" "	" "	73xx	" "	" "
1650	" "	" "	30xx	xx3, xx-	AF,AA,--
1660	" "	" "	43xx	" "	" " "
1670	" "	" "	48xx	" "	" " "
1680	" "	" "	59xx	" "	" " "
2620	" "	" "	61xx	" "	" " "
31xx	" "	" "	62xx	" "	" " "
41xx	" "	" "			

Note: x = any character
-- = blank

Table A.2

DEFINITION OF ENGINE COMPONENTS AND ACCESSORIES

FSC	WBS Code	Group Code	Application
2810	not xx6	not SU	Aircraft MDS
2840	" "	" "	"
2915	" "	" "	"
2925	" "	" "	"
2935	" "	" "	"
2945	" "	" "	"
2950	" "	" "	"
2995	" "	" "	"
Any	" "	" "	Engine TMS

Note: x = any character

Table A.3

DEFINITION OF AVIONICS COMPONENTS

FSC	WBS Code	Group Code	FSC	WBS Code	Group Code
12xx	not xx6	not SU	6605	not xx6	not SU
5805	" "	" "	6610	" "	" "
5810	" "	" "	6615	" "	" "
5811	" "	" "	6620	" "	" "
5815	" "	" "	6645	" "	" "
5821	" "	" "	6650	" "	" "
5826	" "	" "	6660	" "	" "
5831	" "	" "	6680	" "	" "
5835	" "	" "	6685	" "	" "
5841	" "	" "	6695	" "	" "
5850	" "	" "	67xx	" "	" "
5855	" "	" "	59xx	xx4	AV
5860	" "	" "	61xx	"	"
5865	" "	" "	62xx	"	"
5895	" "	" "			

Note: x = any character

Table A.4

DEFINITION OF ARMAMENT COMPONENTS

FSC	WBS Code	Group Code
10xx	not xx6	not SU
11xx (not 1190)	" "	" "
13xx (not 1377,1398)	" "	" "
14xx (not 1450)	" "	" "
30xx	xx5	AR
43xx	"	"
48xx	"	"
59xx	"	"
61xx	"	"
62xx	"	"

Note: x = any character

Table A.5

DEFINITION OF SUPPORT EQUIPMENT

FSC	WBS Code	Group Code	FSC	WBS Code	Group Code
1190	any	any	44xx	any	any
1390	"	"	49xx	"	"
1450	"	"	51xx	"	"
17xx	"	"	52xx	"	"
25xx	"	"	6625	"	"
26xx (not 2620)	"	"	6630	"	"
2805	"	"	6635	"	"
2815	"	"	6636	"	"
2835	"	"	6640	"	"
2850	"	"	6665	"	"
2895	"	"	6670	"	"
2910	"	"	69xx	"	"
2920	"	"	70xx	"	"
2930	"	"	74xx	"	"
2940	"	"	81xx	"	"
2990	"	"	Any	xx6	SU
39xx	"	"			

Note: x = any character

EXPLANATORY VARIABLES

The following variables are the potential explanatory variables for which data were collected and analyzed during this study.

Airframe Rework and Airframe Component Repair

Fleet Flying Hours: the number of flying hours accumulated during a year by aircraft of a particular MDS.

Inventory: average number of aircraft of a particular MDS possessed by operating units of the Air Force.

Sorties: the number of sorties flown in a year by aircraft of a particular MDS.

Flying Hours per Aircraft: average annual flying hours per possessed aircraft (fleet flying hours divided by inventory).

Sorties per Aircraft: average number of annual sorties per possessed aircraft (sorties divided by inventory).

Empty Weight: the weight of an aircraft when crew, fuel, oil, armament, cargo, bombs, and disposable or special equipment are excluded (pounds).

Maximum Takeoff Weight: maximum gross weight at takeoff for normal operating conditions (pounds).

Maximum Speed: the highest speed obtainable in level flight at conditions most favorable to speed (knots).

Typical Speed: this is the speed most characteristic of an aircraft's basic mission, e.g., average cruise speed for bombers and transports and combat speed for fighter and attack aircraft (knots).

Typical Altitude: the altitude most characteristic of an aircraft's basic mission (feet).

Dynamic Pressure at Maximum Speed: dynamic pressure evaluated at the aircraft's maximum speed and for the standard atmospheric density corresponding to the altitude for maximum speed.

Dynamic Pressure at Typical Speed: dynamic pressure evaluated at the aircraft's typical speed and at the standard atmospheric density corresponding to its typical altitude (psf).

Maximum Load Factor: the design load factor (g's).

Airframe Manufacturing Cost: cumulative average cost of first 100 units, including manufacturing labor and materials (millions of FY 1978 dollars).

Reserve Percentage: the percentage of the inventory operated by units of the Air Force Reserve or Air National Guard.

Climate Percentage: the percentage of the inventory operating from bases in humid climates.

Organic Maintenance Percentage: the percentage of a cost that is associated with organic maintenance rather than contractor maintenance.

Afterburner Designator: = 1 if aircraft does not have an afterburner, = 2 if aircraft does.

Contractor Designator: dummy variable to identify manufacturer of the aircraft:

1 = Boeing	6 = LTV
2 = Cessna	7 = McDonnell Douglas
3 = Fairchild	8 = North American
4 = General Dynamics	9 = Northrop
5 = Lockheed	10 = Republic

Fighter/Attack Designator: = 1 for fighter and attack aircraft, = 0 for all others.

Bomber/Cargo Designator: = 1 for bomber and cargo aircraft, = 0 for all others.

Trainer Designator: = 1 for trainer aircraft, = 0 for all others.

Complete PDM Designator: = 1 if aircraft has a PDM program, = 0 if it does not.

No PDM Designator: = 1 if aircraft has no PDM program, = 0 if it does.

PDM: as a variable, = 2 if aircraft has a PDM program, = 1 if it does not, = 0 if aircraft in sample is not a clear case of PDM program or no PDM program.

Representative Series Select Code: = 1 for the MDS most representative of an M/D, = 0 for any other MDS.

Age: aircraft average age, as measured and reported by AF/PAXRB (years).

Engine Overhaul, Repair, and Component Repair Analyses

Overhaul Depot: depot responsible for engine overhaul (1 = Oklahoma City; 2 = San Antonio).
Source: AFLC Form 992

Model Qualification Date: date engine passed nonrated 150-hour model qualification date (in months since January 1943).
Source: Gray Book

Turbine Inlet Temperature: maximum turbine inlet temperature (degrees Rankine).
Source: Gray Book

Thrust-to-Weight Ratio: ratio of maximum engine thrust to engine weight.
Source: Current table entries

Pressure Term: product of the maximum dynamic pressure for the flight envelope and the engine's maximum design pressure ratio (lb/sq ft).
Source: N-1242-PA&E, Table 11. Based on discussion with J. R. Nelson, values for engine series were determined by adjusting model pressure term by ratio of series pressure ratio to model pressure ratio.

Specific Fuel Consumption: specific fuel consumption for military power at sea level (lbs/hr/lb).
Source: Gray Book

Maximum Mach #: maximum airplane Mach number at which the engine can operate.
Source: Gray Book

Removal Rate: rate of unscheduled engine removals requiring base maintenance and depot overhaul plus engines removed for periodic inspection per 1000 fleet engine operating hours. It does not include maximum-time engines removed for overhaul or engines removed for non-usage reasons (aircraft accident, modification, removal to facilitate other aircraft maintenance, removal for experimental purposes, etc.).
Source: AFLC Form 992

Unit 1000 Selling Price: selling price for 1000th unit in 1978 dollars.
Source: N-1242-PA&E, Table 49

Weight: dry weight of turbine engine (lbs).
Source: Gray Book

Maximum Thrust: maximum thrust that engine can generate at sea level (with afterburner if engine has one) (lbs).

Military Thrust: maximum thrust that engine can generate at sea level at military power throttle position (lbs).
Source: Gray Book

Annual Sortie Rate per Engine: total annual MDS sorties divided by product of average possessed aircraft and number of engines per aircraft.
Source: HQ USAF/PAXRB

Mission Designator: dummy variable distinguishing engines with bomber/cargo applications (=1) from those with fighter/attack applications (=2).
Source: WSCRS data

Fighter/Attack Designator: dummy variable distinguishing engines on fighter/attack aircraft with air-to-air roles (=1) from those on fighter/attack aircraft with air-to-ground roles (=2).
Source: R-2249-AF, Table A.1

Single Engine Designator: dummy variable distinguishing engines on aircraft with multiple engines (=1) from those on aircraft with only a single engine (=2).
Source: WSCRS data

Reserve/Guard Percentage: percentage of engine operating hours flown by reserve/guard personnel.
Source: Based on data in PA 76-1 and 78-1 (Aerospace Vehicles and Flying Hours)

Turbofan Designator: dummy variable distinguishing turbojets (=1) from turbofans (=2).
Source: Engine nomenclature

Manufacturer Designator: dummy variable distinguishing General Electric (=1) from Pratt & Whitney (=2) engines.
Source: Engine nomenclature

Type Maintenance Designator: dummy variable distinguishing organization performing overhaul (1 = depot, 2 = contractor).
Source: WSCRS data

Maximum Time Between Overhaul: the maximum time (in operating hours) an engine may be retained in service without a major overhaul.
Source: AFLC Form 992

Average Time Between Overhaul: the average age (in operating hours) of all premature and maximum-time engine removals requiring major overhaul.
Source: AFLC Form 992

Installed Engines: serviceable engines physically mounted on an aircraft at end of fiscal year.
Source: AFLC Form 992

Annual Flight Hours per Engine: operating hours flown per engine per year.
Source: AFLC Form 992

Avionics Component Analysis

Suite Weight: weight of electronics group equipment (excluded installation weight) (lbs).
Source: Rand data

Aircraft First Flight Date: first flight date of aircraft series (in months since January 1943).
Source: Green Book

Number of Black Boxes: number of electronic components, or units, usually identifiable by AN designation, which are normally considered part of aircraft's avionics subsystem.
Source: Green Book

Number of Functions: number of electronics functions performed by aircraft's avionics subsystem. Functions counted are:

1. controls/displays/instrumentation
2. communication/identification
3. navigation
4. bomb navigation/fire control
5. reconnaissance
6. ECM

Source: Green Book

Suite Procurement Cost #1: procurement cost of avionics suite at unit 100 ($78).
Source: RM-4851-PR, other Rand data

Suite Procurement Cost #2: sum of current D041 item procurement costs for all items which are assignable to the avionics subsystem.
Source: Data base established for R-2552-PA&E

Mean Time Between OFM Demands: mean time between avionics subsystem demands placed on base-level organizational and field maintenance.
Source: Data base established for R-2552-PA&E

Annual Flying Hours per Aircraft: total annual MDS flying hours divided by average possessed aircraft.
Source: WSCRS

Annual Sorties per Aircraft: total annual MDS sorties divided by average possessed aircraft.
Source: HQ USAF/PAXRB

Peculiar Percent Based on Dollars: percentage of total avionics spares investment managed by flying hours material program which is unique to MDS (%).
Source: R-2552-PA&E, Appendix B

Peculiar Percent Based on Item Count: percentage of total number of recoverable avionics items managed by flying hours material program which is unique to MDS (%).
Source: R-2552-PA&E, Appendix B

Combat Dummy Variable: dummy variable distinguishing noncombat aircraft (=1) from combat aircraft (=2).
Source: Nomenclature

All-Weather Dummy Variable: dummy variable distinguishing aircraft with all-weather capability (=2) from others (=1).
Source: Rand data

Mission Group Dummy Variables: dummy variables distinguishing aircraft mission types.
Source: Nomenclature

GROUP CODES

Group Codes were used in the DMIF Cost Accounting/Production Report prior to FY 1977. Headquarters, Air Force Logistics Command provided the following code definitions:

AF - Airframe Repair
AA - Aircraft Accessory Repair
EA - Engine Accessory Repair
EO - Engine Overhaul
AV - Avionics Repair
AR - Armament Repair
SU - Support Equipment Repair

WORK BREAKDOWN STRUCTURE CODE

The work breakdown structure came into use with the unified cost accounting system in FY 1977. The following codes relate to aircraft or general use:*

A11 - Aircraft, Fighters, Airframe
A12 - Aircraft, Fighters, Engine
A13 - Aircraft, Fighters, Aircraft and Engine Accessories and Components
A14 - Aircraft, Fighters, Electronics and Communications Equipment
A15 - Aircraft, Fighters, Armament
A16 - Aircraft, Fighters, Support Equipment
A17 - Aircraft, Fighters, Other

* Office of the Deputy Assistant Secretary of Defense (Management Systems), Department of Defense Depot Maintenance and Maintenance Support Cost Accounting and Production Reporting Handbook, DoD 7220.29-H, October 21, 1975, Appendix D.

A2** - Aircraft, Bombers*
A3** - Aircraft, Transport
A4** - Aircraft, Trainers
A5** - Aircraft, Utility
KXX - General Purpose Equipment
L11 - All Items Not Identified to Another Category

Work Performance Categories

This study addressed costs charged against eight Work Performance Categories. As defined by DoD,** these are:

Code A -- Overhaul. The disassembly, test, and inspection of the operating components and the basic structure to determine and accomplish the necessary repair, rebuild, replacement and servicing required to obtain the desired performance. It is considered to be synonymous with the terms "rework" and "rebuild."

Code B -- Progressive Maintenance. A predetermined amount of work that represents a partial overhaul under a program that permits the complete overhaul to be accomplished during two or more time periods. It is considered synonymous with the terms "cycle maintenance," "restricted availability," "preventive servicing," or "recondition."

Code C -- Conversion. The alteration of the basic characteristics of an item to such an extent as to change the mission, performance, or capability.

Code G -- Analytical Rework. The disassembly, test, and inspection of end items, assemblies, or subassemblies to determine and accomplish the necessary rework, rebuilding, replacement, or modification required. It includes the technical analysis of the findings and determination of maintenance criteria. Includes prototype teardown, analysis, and rework of an item to determine job and material specifications on a future workload.

Code H -- Modification. The alteration or change of the physical makeup of a weapon/support system, subsystem, component, or part in accordance with approved technical direction.

Code I -- Repair. Action taken to restore to a serviceable condition an item rendered unserviceable by wear, failure, or damage.

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* xx = Any third character.
** DoD 7220.29-H, pp. E-1 and E-2.

Code J -- Inspection and Test. The examination and testing required to determine the condition or proper functioning as related to the applicable specifications.

Code K -- Manufacture. The fabrication of an item by application of labor and/or machines to material.

Other categories exist, but they identify work that either is maintenance support, as opposed to maintenance proper, or is most likely to be connected with systems that are not fully operational, e.g., storage or reclamation work.

Appendix B
DATA PROCESSING

AIRFRAME AND ENGINE DATA

The main effort in development of the airframe rework data base was the fairly straightforward aggregation of data contained in WSCRS files. WSCRS data records contained MDS, WAC, individual cost elements, production quantity, flying hours, and inventory-month data for a fiscal year. Processing consisted of the following steps for each MDS:

1. Drop records for WACs other than those of interest.
2. Sum each cost element across records to compute a subtotal by year, MDS, and WAC.
3. Convert each cost element to FY 1978 dollars.
4. Sum the individual elements to compute a total cost by year.
5. Average the cost, production quantity, flying hour, and inventory-month data, obtaining a single value for each variable representing the three years of raw data.
6. Divide the inventory-month variable by 12 to compute the average inventory size.
7. Explanatory variable data were obtained from several sources and input manually.

Cost data for engine overhaul and repair were also obtained directly from WSCRS, with similar processing. The main difference is that engine costs are associated with the engines themselves rather than with the systems in which the engines are used.

COMPONENT REPAIR

Development of the component repair data base was considerably more complex than the processing of the rework and overhaul data.

The main reason is the necessity of associating data that are recorded by component stock number with the appropriate weapon system (or weapon systems). WSCRS was the primary source of component repair cost data. WSCRS data files provided by the Air Force covered costs for components one indenture below an end item and costs associated with only a Federal Stock Class instead of a complete stock number. These WSCRS data had two features that were important to this study. One was that they identified first-indenture components with the appropriate MDSs and engines. The other was that the lower-indenture components that were not included account, at least for some aircraft, for a significant fraction of the cost of component repair.

Because of this, tapes containing copies of the Air Force's depot maintenance cost accounting data were requested from AFLC. These tapes contained data on all depot maintenance costs for the years of interest to this study. From this data we developed the needed cost information for components below the first indenture. These costs were then included with the cost data taken from WSCRS to produce a complete data base.

Three files with different formats were the basic sources of cost data:

1. WSCRS file of first-indenture component costs.
2. WSCRS file of costs identified by Federal Stock Class.
3. Accounting system data (HO36B).

In addition, data specifying the indenture structure (relating SRUs to LRUs) were obtained from supply system records (D041). The following steps were used to collect all of this information into a single complete data base:

1. Use D041 data to define the complete list of stock numbers used on each MDS and engine, computing the number of each component used on each end item (quantity per application).

2. For each stock number applicable to end items used in the data base, develop from H036B cost records in the same format as the WSCRS records. Add to these records the quantity per application data.
3. Merge the cost records from H036B with the WSCRS files.
4. For the new records, compute and save an allocation factor based on total component operating hours and operating hours on each end item.
5. Process data as described above for airframe and engine data.
6. Separate the file into subfiles for airframe components, engine components and accessories, avionics components, armament components, and support equipment components. The differentiation is based on Federal Stock Class, work breakdown structure, and Group Code as described in App. A.
7. Add to each subfile the explanatory variable data obtained from separate sources.

Appendix C

DEPOT MAINTENANCE COST DATA

Table	Title
C.1	Airframe Rework Total Cost Data
C.2	Elements of Airframe Rework Cost Data
C.3	Elements of Airframe Component Repair Cost Data
C.4	Armament Component Repair Costs
C.5	Elements of Engine Overhaul Cost Data
C.6	Elements of Engine Repair Cost Data
C.7	Elements of Engine Component and Accessory Repair Cost Data
C.8	Elements of Avionics Component Repair Cost Data
C.9	Depot Maintenance Cost Comparison with OSCAR Data

The cost data used in this study are presented in Tables C.1 through C.8, which also show the magnitudes of the individual cost elements associated with each category of depot maintenance activity. When the costs of all activities are combined to give a total annual depot maintenance cost by weapon system, the results are the costs shown in the left-hand column of Table C.9. The other column in this table is a set of corresponding costs taken from output for 1977 from the Air Force's Operating and Support Cost Analysis Report (OSCAR). Differences between the two sets of data are due to differences in the allocation of common component repair costs as well as to the use of a three-year data base in this study, as opposed to the OSCAR annual data base.

Table C.1

AIRFRAME REWORK TOTAL COST DATA

MDS	Total Cost	Cost per Aircraft	Cost per Depot Visit
A007D	4777745	13090	51932
A010A	2717	94	-
A037	1237538	10952	4139
B052D	3010723	33828	143368
B052G	39721537	245195	630501
B052H	20551246	230913	587178
C005A	26469470	407222	715391
C130E	10633790	37843	98461
C141A	24825940	100105	206883
F004C	15254006	56496	98413
F004D	20193799	45482	87419
F004E	28506099	47990	98980
F005B	33003	3667	16502
F005E	915307	17947	17602
F015A	713143	8592	4542
F101B	336762	3007	56127
F105B	580444	17072	5635
F105D	2502250	25275	16907
F105F	585772	30830	24407
F105G	2120858	50497	151490
F106A	9726981	55583	127987
F106B	2161466	58418	39299
F111A	473711	5094	157904
F111D	765696	9115	85077
F111E	820033	10380	410017
F111F	235850	2775	117925
T033A	709208	3138	8059
T037B	1044856	1648	87071
T038A	2606442	2915	6260
T039A	795601	7207	98200
FB111A	208600	3161	34767
KC135	16937623	25938	109275
OV010A	473211	5439	0
RF004C	15600781	45089	73243
TF015A	232582	10572	11075

NOTE: All costs in FY 1978 dollars.

Table C.2

ELEMENTS OF AIRFRAME REWORK COST DATA

MDS	Direct Civilian Labor Cost	Direct Civilian Labor Hours	Direct Military Labor Cost	Direct Military Labor Hours	Other Direct Material Cost	Other Direct Cost	General and Administrative Cost	Other Direct Cost	Contracted Out Depot Maintenance Cost	Production Quantity Completed
A007D	1,838,379	185,795	16,090	1,775	172,621	0	60,956	2,235,771	453,926	92
A010A	892	74	537	70	0	0	79	1,209	0	0
A037	8,929	794	0	438	0	0	712	13,940	1,213,956	299
B052D	1,274,937	121,149	50,264	11,570	50,300	0	91,849	1,543,370	0	21
B052G	18,706,547	1,859,468	166,216	21,675	1,766,032	0	769,943	18,008,132	304,665	63
B052H	9,395,512	881,910	55,106	11,837	946,791	0	467,585	9,638,575	47,676	35
C005A	11,229,163	1,077,419	30,652	13,125	964,801	0	584,902	11,357,200	2,302,751	37
C130E	3,423,559	313,039	66,917	10,789	262,097	0	153,642	3,467,902	3,259,671	108
C141A	11,271,830	1,006,643	117,938	24,364	1,202,601	0	537,037	10,788,194	908,339	120
F004C	4,763,303	446,384	157,779	22,624	849,816	0	234,272	5,044,736	4,204,098	155
F004D	5,492,452	517,739	293,258	38,659	780,850	0	332,007	5,857,699	7,437,531	231
F004E	10,760,039	1,022,289	380,687	49,703	1,339,555	0	583,630	11,393,158	4,049,028	288
F005B	7,522	651	2,933	345	1,385	0	424	15,544	5,194	2
F005E	173,401	15,220	41,273	3,427	14,599	0	9,456	291,106	385,471	52
F015A	201,289	17,648	29,411	5,117	7,803	6,055	15,288	255,142	198,155	157
F101B	31	3	7,998	1,167	0	0	3	9,839	318,890	6
F105B	11,069	995	85	12	0	0	706	9,314	559,268	103
F105D	25,325	2,057	3,263	383	589	0	877	26,366	2,445,828	148
F105F	180,846	15,434	27,506	2,979	28,967	0	5,691	180,515	162,245	24
F105G	901,263	76,073	39,537	4,711	228,642	0	23,975	845,810	81,630	14
F106A	4,443,347	372,635	213,813	24,589	525,619	0	193,157	4,324,133	26,912	76
F106B	983,521	82,027	28,149	3,093	119,940	0	41,891	974,806	13,158	55
F111A	156,120	13,499	58,802	7,471	2,635	0	8,453	247,699	0	3
F111D	287,715	24,918	54,379	5,397	93,660	0	16,578	313,363	0	9
F111E	228,529	19,235	159,019	17,046	14,043	0	13,560	404,881	0	2
F111F	89,171	7,437	34,303	3,952	1,083	0	5,329	105,963	0	2
T033A	27,836	2,359	478	50	2,257	0	840	19,791	658,004	88
T037B	164,924	15,426	57,175	17,711	0	0	15,077	399,815	407,863	12
T038A	250,361	22,525	13,678	2,513	31,272	0	912	264,908	2,035,309	406
T039A	71,139	6,104	9,176	1,146	16,307	0	3,218	83,597	610,163	8
FB111A	93,991	8,238	12,067	1,376	9,632	0	3,389	89,520	0	6
KC135	1,192,587	113,930	31,470	4,387	135,440	0	76,680	1,306,249	14,193,194	155
OV010A	152.300	13,158	82,388	9,867	5,680	0	9,221	223,622	0	0
RF004C	5,797,257	546,196	130,403	18,280	835,071	0	349,754	5,851,334	2,636,960	213
TF015A	67,810	5,796	6,150	774	6,750	0	6,207	83,157	62,503	21

Note: All costs in FY 1978 dollars.

Table C.3

ELEMENTS OF AIRFRAME COMPONENT REPAIR COST DATA

MDS	Total Cost	Cost Per Aircraft	Direct Civilian Labor Cost	Direct Civilian Labor Hours	Direct Military Labor Cost	Direct Military Labor Hours	Other Direct Material Cost	Other Direct Cost	General and Administrative Cost	Other Indirect Cost	Contracted Out Depot Maintenance Cost	Production Quantity Completed
A-7D	1,837,725	5,035	352,862	33,450	3,959	684	697,742	0	23,848	340,951	418,349	5,967
A-10A	11,290	389	2,985	275	30	9	1,263	0	283	2,985	3,741	101
A-37	236,965	2,097	45,555	4,151	1,226	180	67,239	0	7,123	36,888	78,928	1,154
B-52D	5,564,362	62,521	1,622,498	157,297	6,065	1,096	1,586,144	0	101,328	1,631,579	16,717	11,352
B-52G	11,359,504	70,120	3,684,655	362,764	16,[illegible]05	2,782	3,159,590	0	220,201	3,656,278	622,248	18,134
B-52H	6,559,148	73,698	1,896,788	182,207	13,428	2,087	2,178,501	0	135,902	1,819,199	515,301	12,824
C-5A	9,959,363	153,221	2,273,825	223,565	3,437	1,269	3,609,638	0	186,024	2,367,913	1,518,494	21,592
C-130E	9,600,276	34,165	2,535,189	235,897	15,764	2,252	3,478,214	0	125,549	2,284,091	1,159,780	21,394
C-141A	15,324,083	61,791	4,943,645	464,527	17,577	2,984	4,464,795	0	278,386	4,986,835	632,834	25,354
F-4C	4,326,013	16,022	1,195,801	115,035	7,211	1,137	1,342,354	0	80,336	1,173,368	526,886	10,763
F-4D	7,181,913	16,175	1,890,105	182,409	10,038	1,617	2,595,674	0	128,405	1,884,146	673,537	14,890
F-4E	8,673,675	14,602	2,237,139	214,731	10,738	1,788	3,226,212	0	151,325	2,252,166	796,086	19,296
F-5B	179,585	19,954	23,634	2,163	355	51	56,612	0	3,210	23,250	72,519	536
F-5E	171,311	3,359	31,149	2,786	1,088	164	55,860	0	6,080	25,043	52,087	760
F-15A	434,550	5,115	27,150	2,551	539	135	51,108	0	2,868	25,807	327,076	1,210
F-101B	1,168,821	10,436	306,955	29,246	3,009	500	405,550	0	25,185	288,723	139,381	4,394
F-105B	500,586	14,723	139,010	12,529	1,998	280	110,241	0	10,408	121,851	117,070	1,881
F-105D	1,211,652	12,239	377,411	34,507	4,078	583	273,880	0	21,957	341,947	192,372	3,783
F-105F	376,861	19,835	94,591	8,465	1,527	214	83,987	0	10,497	81,542	104,707	1,851
F-105G	625,569	14,895	179,022	16,204	2,209	308	144,582	0	13,669	157,068	129,012	2,325
F-106A	4,395,852	25,119	1,256,327	110,890	16,393	2,244	1,609,118	0	83,495	1,116,931	[illegible]	12,491
F-106B	1,504,018	40,649	449,257	39,068	5,807	842	530,399	0	43,918	372,464	102,156	4,852
F-111A	2,299,807	24,729	673,484	59,199	9,893	1,297	615,292	0	49,898	627,979	323,248	6,046
F-111D	2,366,888	28,177	625,433	54,890	8,791	1,188	608,581	0	47,577	586,877	489,607	5,587
F-111E	2,420,182	30,635	779,482	68,747	10,204	1,323	661,115	0	52,708	721,261	195,399	6,126
F-111F	2,549,836	29,998	782,919	68,733	11,153	1,450	761,502	0	52,565	736,145	205,534	6,653
T-33A	762,866	3,376	189,517	17,411	2,665	368	81,283	0	13,120	181,225	295,050	5,959
T-37B	981,105	1,547	163,936	15,016	2,422	377	70,241	0	12,830	148,961	582,709	6,132
T-38A	1,922,604	2,205	317,938	29,424	2,872	495	206,422	0	18,766	320,266	1,056,334	10,530
T-39A	801,294	7,351	154,284	14,147	2,571	383	174,106	0	11,858	141,308	317,162	4,078
FB-111A	1,948,189	29,518	632,032	54,854	9,760	1,280	518,339	0	39,730	594,800	153,521	3,658
KC-135	8,270,538	12,665	1,933,531	184,652	8,625	1,499	2,300,527	0	110,142	1,845,070	2,072,652	28,350
OV-10A	133,886	1,539	18,980	1,729	287	43	5,230	0	1,058	17,676	90,651	619
RF-4C	6,377,423	18,432	1,646,694	158,752	8,426	1,438	2,372,345	0	117,070	1,637,598	595,276	13,380
TF-15A	268,285	12,195	9,540	906	8	32	23,930	0	1,318	8,923	224,561	853

Note: All costs in FY 1978 dollars.

Table C.4

ARMAMENT COMPONENT REPAIR COSTS

(In $ FY 1978)

MDS	Cost per Aircraft
B-52D	2027
B-52G	4505
B-52H	4040
F-101B	31
F-106A	547
F-106B	1651

Table C.5

ELEMENTS OF ENGINE OVERHAUL COST DATA

(Costs in $ 1978)

	Direct Civilian Labor Cost	Direct Civilian Labor Hours	Direct Military Labor Cost	Direct Military Labor Hours	Other Direct Material Cost	Other Direct Cost	General and Administrative Cost	Other Indirect Cost	Contracted Out Depot Maintenance Cost	Total Cost	Number of Overhauls	Average Cost per Overhaul
J33-A-35	0	0	0	0	0	0	0	0	90169	90169	38	2373
J57-P-13A/B	0	0	0	0	0	0	0	0	3863	3863	1	3863
J57-P-19/19W	739902	75946	10777	1527	485588	0	33591	979671	0	2249531	62	36283
J57-P-21	542062	58647	5798	904	381790	0	20464	689137	20887	1660139	51	32552
J57-P-43	1585563	168597	19427	3379	912836	0	41971	2054373	0	4614172	156	29578
J57-P-55/55A	0	0	0	0	0	0	0	0	846565	846565	26	32560
J57-P-59W	100516	11301	307	59	97701	0	3127	125982	8723957	9051589	257	35220
J60-P-3/3A	0	0	0	0	0	0	0	0	470922	470922	53	8885
J65-W-5F	0	0	0	0	0	0	0	0	725795	725795	42	17280
J69-T-25	0	0	0	0	0	0	0	0	1106285	1106285	260	4255
J75-P-17	460394	47722	8508	1467	431314	0	23288	625755	0	1549261	49	30618
J75-P-19/19W	421441	44007	8874	1467	295242	0	18583	588757	0	1332897	43	30998
J79-GE-15	5839165	585225	9227	2097	5831889	0	334905	5948730	0	17963915	462	38883
J79-GE-17/17A	3135598	327622	5942	1087	1789817	0	160504	3297972	0	8389829	267	31423
J85-GE-5H	0	0	0	0	0	0	0	0	1790484	1790484	175	10231
J85-GE-13	0	0	0	0	0	0	0	0	25497	25497	3	8499
J85-GE-21	0	0	0	0	0	0	0	0	8821	8821	0	∞
TF30-P-3	2026343	215041	19661	2744	2062377	0	86965	2381360	0	6576704	128	51380
TF30-P-7	681634	71536	6770	974	626652	0	26178	831451	0	2172686	51	42602
TF30-P-9	349927	35139	4504	550	466399	0	20129	428497	0	1269456	22	57702
TF30-P-100	1274601	133778	12893	1854	2117554	0	51213	1481157	0	4937420	77	64122
TF33-P-3	471021	49185	3803	568	431914	0	22230	621293	0	1550261	53	29250
TF33-P-5	87135	9349	578	93	79818	0	3664	114387	0	285584	10	28558
TF33-P-7/7A	994223	103376	8626	1316	781136	0	45420	1311441	0	3140847	119	26394
TF33-P-9	76181	7885	668	93	66407	0	4576	94135	0	241969	9	26885
TF34-GE-100	726983	72702	190	31	423493	0	27378	860841	0	2038885	46	44324
TF39-GE-1/1A	2516320	262560	26267	3381	6563850	0	128464	3125353	0	12360256	140	88287
F100-PW-100	6202	608	0	2	2319	0	559	6507	151095	166684	3	55561
F100-PW-23A	2674	250	6	3	6261	0	158	2790	0	11890	0	∞
F100-PW-23B	5148	508	1	2	26231	0	282	4955	135423	172042	3	57347
F100-PW-23C	69	6	0	1	0	0	7	77	100250	100404	6	16734
F100-PW-23F	13118	1317	0	2	20057	0	1390	13589	0	48155	4	12039
F100-PW-23G	529	50	0	1	665	0	30	599	8771	10594	4	2648
T56-A-7B	1129733	112508	2705	6391	928466	0	58212	1207799	0	3326917	287	11592
T56-A-9B	444765	44382	848	280	427542	0	18469	479415	0	1371040	98	13990
T56-A-15	344514	34175	1154	257	211855	0	16346	361923	0	935792	64	14622
G56-A-9B	471599	46804	535	145	517498	0	21459	479299	0	1490392	123	12117
G56-A-15	1235979	123979	2033	381	1333949	0	64448	1260927	0	3897338	436	8938

[a] With e ception of avera ost per overhaul, all values are *annual* averages for 1975-1977 time pe .

Table C.6

ELEMENTS OF ENGINE REPAIR COST DATA[a]

Engine	Direct Civilian Labor Cost	Direct Civilian Labor Hours	Direct Military Labor Cost	Direct Military Labor Hours	Other Direct Material Cost	Other Direct Cost	General & Admin. Cost	Other Indirect Cost	Contracted Out Depot Maintenance Cost	Total Cost	Installed Engine	Cost Per Engine	Number Of Repairs	Average Cost per Repair
J33-A-35	16285	1532	463	64	1877	0	629	21566	2102	42923	207	207	5	8850
J57-P-19W/29WA	28933	2993	3109	373	826	0	1169	50263	0	84301	1018	83	28	3010
-21A/B	73051	7350	73197	10984	7555	0	6308	215976	0	376088	356	1056	51	7374
-43WB	88917	9262	12935	2020	23459	0	3852	176636	0	305800	1601	191	106	2880
-55/55A	2051	187	1718	253	0	0	235	5504	95468	104978	218	482	5	21000
-59W	9432	986	19840	2803	395	0	903	41323	4201	76096	2613	29	3	25400
J60-P-3/3A	10925	1064	1297	146	3348	0	378	13747	0	29696	261	114	1	29700
J69-P-25	94	7	0	0	0	0	4	171	572	842	1397	1	1	840
J75-P-17	83674	8077	38303	5220	40441	0	6015	184610	0	352445	199	1771	22	16000
-19/19W	108917	10759	25770	3409	19219	0	5373	185984	0	345263	194	1782	40	8640
J79-6E-15	182482	18408	3202	777	4000	0	10875	193923	0	394484	2112	187	111	3550
-17/17A	100325	10086	1670	291	33108	0	5245	129017	0	269366	1286	209	52	5180
J85-6E-5H	0	0	0	0	0	0	0	0	3137	3137	1831	2	1	3140
-13	0	0	0	0	0	0	0	0	6919	6919	23	301	1	6920
-21	0	0	0	0	0	0	0	0	48421	48521	201	241	5	9700
TF30-P-3	590195	58023	70590	8474	66403	0	33359	887616	0	1647965	313	5265	270	2400
-7	175831	17000	4375	550	12288	0	11001	262399	0	465896	116	4016	32	14600
-9	130262	12629	3008	380	3385	0	8333	194127	0	339116	147	2307	20	17000
-100	243829	23771	4760	620	3296	0	13422	307421	0	572729	174	3292	51	11200
TF33- -3	40160	4118	14111	1656	963	0	1938	74821	0	131996	735	180	44	3000
-5	45872	4159	15115	1804	8895	0	2065	69205	0	141153	100	1412	2	70600
-7/7A	80241	8238	9559	1112	3277	0	2985	122510	0	218573	1095	200	40	5460
-9	8197	760	13467	1725	6706	0	784	26816	0	55972	103	543	2	28000
TF39-6E-1/1A	251820	24759	468	101	2259	0	13699	290698	0	538945	277	2018	38	14700
TF41-A-1/1A	21[illegible]	215868	53148	6957	787452	0	103334	3145351	0	6206592	354	17532	[illegible]	14268
F100-PW-100	5[illegible]6	5368	1655	236	326518	0	36000	592628	0	1509008	338	1506	19	26800
-23A	[illegible]64	4740	76	18	31197	0	4856	52536	0	135929	338	402	19	7150
-23B	140828	14148	694	95	374537	0	14821	155244	0	686125	338	2030	21	32700
-23C	7926	785	18	6	10939	0	712	8332	0	27929	338	83	4	6980
-23F	7631	735	0	1	18244	0	553	6931	0	33360	338	99	2	16700
-23G	4983	507	38	10	9731	0	522	5481	0	20756	338	61	6	3460
T56-A-7B	75677	7384	315	60	4696	0	4699	83918	0	170307	1596	107	53	3210
-9B	44138	4345	177	43	1531	0	2152	49128	0	97127	549	177	68	1430
-15	25127	2421	86	21	1182	0	1469	26479	0	54344	542	100	19	2860
G56-A-7B	447	25	0	0	0	0	16	423	0	886	[illegible]	1	1	890
-9B	23824	298	52	15	1637	0	994	24913	0	51422	547	94	44	1170
-15	36508	3312	112	25	983	0	1750	37558	0	76914	1276	60	60	1280

[a] With exception of average cost per repair, all values are *annual* averages for 1975-1977 time period.

Table C.7

ELEMENTS OF ENGINE COMPONENT AND ACCESSORY REPAIR COST DATA[a]
(Costs in $ 1980)

Engine (TMS)	Direct Civilian Labor Cost	Direct Civilian Labor Hours	Direct Military Labor Cost	Direct Military Labor Hours	Other Direct Material Cost	Other Direct Cost	General and Administrative Cost	Other Indirect Cost	Contracted Out Depot Maintenance Cost	Total Cost
J33-A-35	105	10	0	0	200	0	4	101	961	1574
J57-P-13A/B	1729	179	2	0	1161	0	61	1759	3453	5168
-19W/29WA	2048	207	1	0	1235	0	139	2029	5610	11066
-21A/B	2573	262	3	0	2329	0	112	2600	4672	12291
-23B	1326	141	0	0	979	0	37	1298	4151	7795
-43WB	2094	216	2	0	2058	0	92	2080	1944	8273
-55/55A	4270	441	1	1	2163	0	272	4114	13728	24551
-59W	1395	141	0	0	1014	0	75	1385	1866	5738
J60-P-3/3A	224	22	0	0	461	0	7	215	2415	3325
J65-W-5F	18	2	0	0	37	0	0	17	25	98
J69-T-25	64	6	0	0	118	0	2	63	663	912
J75-P-17	8872	899	13	3	12500	0	444	8918	7734	38486
-19/19W	6277	639	8	2	6869	0	355	6289	5927	25730
J79-6E-15	2822	285	1	0	2811	0	149	2719	522	9030
-17/17A	2459	250	1	0	2356	0	133	2385	262	7598
J85-6E-5H	51	5	0	0	85	0	2	50	1360	1550
-13	44	4	0	0	97	0	1	41	7025	7209
-17A	94	9	0	0	183	0	5	89	943	1314
-21	12	1	0	0	15	0	0	11	363	402
TF30-P-3	5498	550	2	0	5882	0	262	5731	9820	27198
-7	6336	636	4	1	7251	0	281	6627	7243	27745
-9	3357	331	2	0	4038	0	171	3458	4623	15653
-100	5075	512	2	1	13068	0	232	5236	5000	28615
TF33-P-3	1270	130	0	0	1528	0	51	1291	1745	5888
-5	1	0	0	0	0	0	0	1	1	4
-7/7A	2907	296	1	0	2878	0	132	2928	4755	13604
-9	3	0	0	0	0	0	0	2	4	10
TF34-6E-100	608	57	20	2	112	0	55	607	2279	3684
TF39-6E-1A	13647	1364	10	3	11441	0	668	13984	4021	43774
TF41-A-1/1A	3236	325	1	0	5183	0	154	3398	11806	24783
F100-PW-100	523	51	1	1	3226	0	53	514	3608	7926
-23A	21	2	0	0	79	0	2	22	3	126
-23B	13	1	0	0	11	0	1	12	3	41
-23C	3	0	0	0	0	0	0	3	2	10
-23F	313	31	1	0	2980	0	32	317	279	3923
-23G	3	0	0	0	3	0	0	4	1	12
T56-A-7B	1743	174	1	0	2142	0	98	1693	70	5747
G56-A-7B	17	2	0	0	23	0	1	18	0	59
T76-6E-10A	73	8	1	0	113	0	3	72	773	1035
-12A	75	8	1	0	116	0	3	73	743	1011

[a]All values are averages for 1975-1977 time period and are on a per installed engine basis.

Table C.8

ELEMENTS OF AVIONICS COMPONENT REPAIR COST DATA:
ANNUAL AVERAGES FOR 1975-1977

(Costs in $ 1978)

MSD	Direct Civilian Labor Cost	Direct Civilian Labor Hours	Direct Military Labor Cost	Direct Military Labor Hours	Other Direct Material Cost	Other Direct Cost	General and Admini-strative Cost	Other Indirect Cost	Contracted Out Depot Maintenance Cost	Total Cost	Aircraft Inventory	Cost per Aircraft
A-7D	1,724,208	155,976	1,877	652	907,144	12	213,518	1,484,959	2,876,595	7,208,366	365	19,749
A-10A	27,839	2,467	3	21	16,078	1	3,085	20,364	90,788	158,166	29	5,454
A-37	92,704	8,355	2	73	79,112	2	4,744	7,013	229,945	476,646	113	4,218
B-52D	2,491,470	233,536	4 967	1,717	2,725,020	3	138,128	2,081,465	1,449,717	8,890,868	89	99,897
B-52G	5,521,198	517,979	6,129	2,675	6,383,974	7	297,517	4,637,230	2,074,307	18,920,464	162	116,793
B-52H	4,258,718	398,873	8,449	2,641	4,898,452	4	239,161	3,553,163	1,353,836	14,311,897	89	160,808
C-5A	3,591,192	326,549	2,774	1,489	3,874,767	5	413,180	3,073,089	7,886,259	18,841,344	65	289,866
C-130E	6,325	598	5	2	6,656	0	317	5,305	1,781	20,393	281	40,859
C-141A	7,039,255	657,022	8,030	2,533	5,847,858	33	339,333	5,879,643	1,521,226	20,635,440	248	83,207
F-4C	3,652,035	333,104	7,423	1,501	2,615,284	6	879,906	2,746,354	436,901	10,337,976	270	38,288
F-4D	4,942,716	447,985	9,843	1,906	3,740,167	11	1,010,807	3,758,200	638,646	14,099,454	444	31,755
F-4E	6,154,509	556,686	11,312	2,322	4,452,603	19	1,175,715	4,725,840	887,909	17,407,968	594	29,306
F-5B	93,196	8,753	9	54	53,839	0	4,680	80,268	28,054	260,062	9	28,895
F-5E	143,279	13,208	37	70	78,175	2	7,462	118,046	505,555	852,573	51	16,717
F-15A	110,615	9,986	5	88	156,188	3	8,438	93,967	318,749	687,989	83	8,289
F-101B	674,382	62,635	463	169	642,719	1	28,847	554,011	491,881	2,392,325	112	21,360
F-105B	336,132	31,225	234	214	395,755	1	18,571	274,786	30,726	1,056,220	34	31,065
F-105D	1,043,975	95,249	1,020	596	1,132,998	2	85,741	860,799	120,354	3,244,911	99	32,777
F-105F	326,352	30,002	208	204	336,754	0	18,499	257,811	22,899	962,544	19	50,660
F-105G	569,420	52,481	361	313	589,768	1	32,766	449,269	161,184	1,802,796	42	42,923
F-106A	3,764,321	349,540	2,254	1,246	4,343,435	6	201,361	3,314,377	488,713	12,114,567	175	69,226
F-106B	1,420,229	131,973	266	541	1,746,015	1	67,680	1,251,474	288,435	4,774,205	37	129,032
F-111A	2,468,716	224,418	11,335	2,883	3,256,924	2	330,326	1,993,416	1,044,020	9,104,878	93	97,902
F-111D	2,711,330	241,630	4,169	2,497	4,545,541	2	360,863	2,327,200	4,847,524	14,796,994	84	176,154
F-111E	2,628,100	237,967	10,648	2,776	3,618,386	2	340,054	2,129,210	1,179,821	9,906,356	79	125,397
F-111F	2,651,176	236,820	5,723	2,354	3,078,747	2	358,226	2,249,844	1,603,691	9,947,632	85	117,030
T-33A	507,649	47,561	311	128	266,802	6	18,984	417,032	204,614	1,415,413	226	6,262
T-37B	921,391	87,645	467	187	651,443	31	36,958	761,346	541,535	2,913,188	634	4,595
T-38A	1,840,994	167,197	5,819	811	1.236,586	38	111,292	1,377,523	2,356,833	6,929,105	872	9,946
T-39A	846,273	79,250	335	248	579,318	10	35,186	668,959	533,445	2,663,555	109	24,436
FB-111A	2,297,746	205,714	3,537	2,241	2,685,708	2	326,213	1,938,050	1,744,590	8,996,025	66	136,303
KC-135A	5,295,872	507,282	5,999	2,089	4,328,101	21	259,272	4,509,418	1,002,255	15,401,051	653	23,585
OV-10A	332,974	30,943	103	165	176,695	3	15,922	268,027	388,114	1,131,857	87	13,010
RF-4C	6,140,542	570,342	6,878	2,314	4,780,359	10	1,001,956	4,875,021	957,927	17,762,816	346	51,338
TF-15A	48,886	4,379	1	51	67,903	0	3,784	39,115	185,953	345,652	22	15,711

Table C.9

DEPOT MAINTENANCE COST COMPARISON WITH OSCAR
DATA: ANNUAL COST PER AIRCRAFT

(In $ thousand 1978)

MDS	Current Data Base	OSCAR Data for 1977
A-7D	145	156
B-52D	320	664
B-52G	535	422
B-52H	551	623
C-5A	1109	965
C-141A	317	300
F-4C	146	165
F-4D	129	166
F-106A	201	266
F-106B	279	260
F-111A	229	414
F-111E	280	370
F-111F	309	269
T-33A	15	15
T-37B	11	7
T-38A	20	24
T-39A	53	57
KC-135	105	92
RF-4C	153	172

Appendix D

EXPLANATORY VARIABLE DATA

Table D.1

AIRFRAME EXPLANATORY VARIABLE VALUES

MDS	Fleet Flying Hours	Inventory	Sorties	Flying Hours per Aircraft	Sorties Per Aircraft	Empty Weight (pounds)	Maximum Takeoff Weight (pounds)	Maximum Speed (knots)	Typical Speed (knots)
A007D	94556	365	50929	259	140	19733	39325	576	530
A010A			6436	458	222	18856	46270	389	376
A037	28537	113	20172	253	179	6008	14000	416	403
B052D	31752	89	4156	357	47	177816	450000	551	453
B052G	69240	162	8692	427	54	168445	488000	551	453
B052H	38182	89	4655	429	52	172740	488000	547	453
C005A	44430	65	9072	684	140	320085	732500	494	447
C130E	170188	281	59698	606	212	71992	155000	325	291
C141A	277727	248	75504	1120	304	134203	323100	496	422
F004C	62261	270	39791	231	147	28539	59689	1180	776
F004D	106309	444	66579	239	150	28873	59483	1180	776
F004E	152329	594	99929	256	168	30328	61795	1221	759
F005B	3260	9	244	362	272	8351	20116	712	558
F005E	12121	51	11134	238	218	9588	21818	866	625
F015A	18544	83	12975	223	156	25780	53300	1434	893
F101B	26779	112	12834	239	115	28492	52400	950	530
F105B	8015	34	4948	236	146	25855	52000	1195	750
F105D	21645	99	13336	219	135	26855	52838	1192	726
F105F	3921	19	2616	206	138	30419	54580	773	681
F105G	8818	42	5409	210	129	31279	54580	723	681
F106A	53969	175	30363	308	174	24861	41831	1153	588
F106B	11532	37	9327	312	252	25696	42720	1153	588
F111A	17602	93	6628	189	71	46172	91300	1262	794
F111D	16837	84	5667	200	67	46631	100000	1262	794
F111E	20010	79	6726	253	85	47000	100000	1262	794
F111F	21609	85	7198	254	85	47481	100000	1262	794
T033A	64234	226	41724	284	185	8365	15100	430	376
T037B	291079	634	217043	459	342	4067	6580	352	278
T038A	350926	872	275056	402	295	7410	11761	699	502
T039A	101996	109	58212	936	534	9753	18650	461	436
FB111A	17520	66	4610	265	70	47481	114300	1262	444
KC135	212491	653	44346	325	68	97030	261000	527	511
OV010A	29159	87	15675	335	180	7033	14444	247	177
RF004C	91975	346	50075	265	145	28546	58000	1196	1204
TF015A	5436	22	2765	247	126	26289	53300	1434	893

Table D.1--continued

MDS	Typical Altitude (feet)	Dynamic Pressure at Maximum Speed (psf)	Dynamic Pressure at Typical Speed (psf)	Maximum Load Factor(g's)	Airframe Manufacturing Cost (78$ x 10^{-3})	Reserve Percent	Climate Percent	Organic Maint. Percent Rework	Organic Maint. Percent Component Repair
A007D	100	913	953	7.0	193	25	52	90	77
A010A	100	379	479	7.3	333	1	97	100	66
A037	100	362	551	6.0	-	96	77	2	66
B052D	33200	545	231	2.4	1936	1	89	100	89
B052G	31700	533	245	3.4	1936	1	71	99	94
B052H	31950	474	242	2.8	1936	1	88	99	92
C005A	29000	371	263	2.3	4320	1	55	91	84
C130E	21200	204	149	2.5	700	16	100	69	88
C141A	39375	374	152	2.5	1167	1	67	96	95
F004C	100	1460	2042	8.5	822	13	53	72	87
F004D	100	1460	2042	8.5	822	1	56	63	90
F004E	100	1566	1954	8.5	822	1	88	85	90
F005B	50000	508	160	7.3	-	1	33	84	59
F005E	50000	750	201	7.3	-	1	90	58	69
F015A	10000	1344	1997	7.3	-	1	59	72	24
F101B	51000	947	137	6.8	461	85	100	5	88
F105B	100	1429	1908	8.7	719	100	52	3	76
F105D	100	1421	1789	8.7	719	100	100	2	84
F105F	100	599	1572	8.7	719	80	100	72	72
F105G	100	525	1572	8.7	719	1	10	96	79
F106A	50650	1395	174	7.0	503	36	91	97	92
F106B	50600	1395	174	6.0	503	36	95	99	93
F111A	100	650	2139	7.3	1098	1	18	100	86
F111D	100	799	2139	7.0	1098	1	8	100	79
F111E	100	799	2139	7.3	1098	1	94	100	92
F111F	100	719	2139	7.3	1098	1	31	100	92
T033A	40000	819	319	7.3	-	10	97	7	61
T037B	25000	194	117	6.7	-	1	70	61	40
T038A	40000	311	117	7.3	160	1	65	22	45
T039A	38000	488	208	3.0	163	2	91	23	60
FB111A	23200	322	174	3.0	-	1	99	100	92
KC135	35000	411	274	2.0	827	4	71	16	75
OV010A	5000	178	91	8.0	-	1	100	100	-
RF004C	40050	1500	1201	8.5	822	18	97	83	90
TF015A	10000	1344	1997	7.3	-	1	97	73	16

Table D.1--continued

MDS	Afterburner Designator	Contractor Designator	Fighter/ Attack Designator	Bomber/ Cargo Designator	Trainer Designator	PDM Designators: Complete	PDM Designators: None	PDM Designators: PDM	Repres. Series Select Code	Age (years)
A007D	1	6	1	0	0	0	0	0	1	4.4
A010A	1	3	1	0	0	0	0	0	1	-
A037	1	2	1	0	0	0	0	0	1	5.3
B052D	1	1	0	1	0	1	0	2	0	19.3
B052G	1	1	0	1	0	1	0	2	1	16.8
B052H	1	1	0	1	0	1	0	2	0	14.8
C005A	1	5	0	1	0	0	0	0	1	5.0
C130E	1	5	0	1	0	1	0	2	1	10.7
C141A	1	5	0	1	0	1	0	2	1	10.1
F004C	2	7	1	0	0	1	0	2	0	11.8
F004D	2	7	1	0	0	1	0	2	0	9.6
F004E	2	7	1	0	0	1	0	2	1	5.8
F005B	2	9	1	0	0	0	0	0	0	2.3
F005E	2	9	1	0	0	0	0	0	1	1.2
F015A	2	7	1	0	0	0	1	1	1	0.2
F101B	2	7	1	0	0	0	1	1	1	11.6
F105B	2	10	1	0	0	0	0	0	0	0.0
F105D	2	10	1	0	0	0	0	0	1	0.0
F105F	2	10	1	0	0	0	0	0	0	12.3
F105G	2	10	1	0	0	0	0	0	0	12.4
F106A	2	4	1	0	0	1	0	2	1	16.7
F106B	2	4	1	0	0	1	0	2	0	16.7
F111A	2	4	1	0	0	0	1	1	0	7.9
F111D	2	4	1	0	0	0	1	1	1	8.1
F111E	2	4	1	0	0	0	1	1	0	4.1
F111F	2	4	1	0	0	0	1	1	0	6.2
T033A	1	5	0	0	1	0	0	0	1	18.5
T037B	1	2	0	0	1	0	1	1	1	14.3
T038A	2	9	0	0	1	0	1	1	1	10.6
T039A	1	8	0	0	1	0	0	0	1	14.1
FB111A	2	4	1	0	0	0	1	1	0	6.0
KC135	1	1	0	1	0	1	0	2	1	15.6
OV010A	1	8	0	0	0	0	1	1	1	8.0
RF004C	2	7	1	0	0	1	0	2	0	7.8
TF015A	2	7	1	0	0	0	1	1	0	0.4

Table D.2

ENGINE EXPLANATORY VARIABLE VALUES

Engine	Application	Responsible Depot[a]	MQT (Months since January 1943)	Technical/Performance: Turbine Inlet Temperature (°R)	Thrust-to-Weight Ratio	Pressure Term (lbs/ft²)	Specific Fuel Consumption (lb/hr/lb)	Maximum Mach	Removal Rate (1975-77 average)	Unit 1000 Selling Price ($ 78)	Size: Weight (lbs)	Maximum Thrust (lbs)	Military Thrust (lbs)	Application: Annual Sortie Rate (1975-77 average)	Mission Designator[b]	Fighter/Attack Designator[c]	Single Engine Designator[d]	Reserve/Guard Percentage (1975-1977 average)	Miscellaneous: Turbofan Designator[e]	Manufacturer Designator[f]	Type Maintenance Designator
J33-A-35	T-33A	1	60	1960	2.5	3400	1.140	1.0	8.44		1820	4,600	4,600	211	2	-	2	19	1	-	2
J57-P-13A/B	RF-101C	1	150	2060	3.0	11400	0.835	1.4	3.40		4920	15,000	10,200	169	2	1	1	100	1	2	2
J57-P-19W/29WA	B-521B/D	1	152	2060	2.6	11400	0.795	1 4	1.13		3970	10,500	10,500	35	1	-	1	0	1	2	1
J57-P-21A/B	F-100D/F	1	147	2060	3.1	11400	0.835	1 4	5.34		[illegible]160	16,000	10,200	145	2	1	2	100	1	2	1
J57-P-23B	F/TF-102A	1	177	2060	3.1	11400	0 835	1.4	3.64		5210	16,000	10,200	166	2	1	2	100	1	2	1
J57-P-43WB	B-52C/F/G C/EC/KC-135A	1	180	2060	2.9	12100	0.775	1.4	1.37		3870	11,200	11,200	55	1	-	1	0	1	2	1
J57P-55/55A	F-101B/F	1	176	2060	3 2	12100	0.830	1.4	3.19		5215	16,900	10,700	183	2	1	1	85	1	2	2
J57P-59W	EC/KC/RC-135A KC/-135Q,RC-135D	1	180	2060	2.6	12100	0.775	1.4	1.78		43[illegible]0	11,200	11,200	70	1	-	1	5	1	2	2
J60-P-3/3A	T-39A	2	212	2060	6.5	10360	0 960	2.0	1.43		460	3,000	3,000	467	2	-	1	0	1	2	2
J65-W-5F	B-57B/C/E	2	136	2030	2.6	8500	0.920	1.8	2.33		2814	7,220	7,200	236	1	-	1	7	1	-	2
J69-T-25	T-37B	2	198	1985	2.8	3400	1.140	1.2	2.44		367	1,025	1,025	323	2	-	1	0	1	-	2
J75-P-17	F-106A/B	1	186	2070	4.2	16724	0.820	2.0	5.00		5875	24,500	16,100	201	2	1	2	34	1	2	1
J75-P-19/19W	F-105B/D/F/G	1	184	2070	4.2	16724	0.820	2.0	4 33		5950	24,500	16,100	138	2	[illegible]	2	78	1	2	1
J79-GE-15	F-4C/D,RF-4C	1	184	2160	4.5	18056	0.860	2.0	2.31		3685	17,000	10,900	153	2	1	1	11	1	1	1
J79-GE-17/17A	F-4E/G	1	238	2235	4.6	18900	0.840	2.0	2 18		3635	17,820	11,810	164	2	1	1	0	1	1	1
J85-GE-5H	T-38A	2	234	2130	6.6	10360	1.030	2.0	3.59	PRIVILEGED INFORMATION	584	3,850	2,680	313	2	-	1	0	1	1	2
J85-GE-13	F-5A/B	2	250	2160	6.8	10360	1 030	2.0	6.85		597	2,720	2,160	242	2	1	1	0	1	1	[illegible]
J85-GE-17A	A-37A/B	2		2175	7.1	10360	0.990	1.0	3.52		400	2,850	2,850	144	2	2	1	92	1	1	2
J85-GE-21	F-5E/F	2	350	2260	7.3	12290	1.000	1.5	6.78		684	5,000	3,500	190	2	1	1	0	1	1	2
TF30-P-3	F-111A/E,FB-111A	1	287	2430	4.6	51340	0.630	2.5	4.76		4062	18,500	10,750	87	2	2	1	0	2	2	1
TF30-P-7	FB-111A	1	315	[illegible]	4.9	52850	0.689	2.2	4.05		4121	20,350	12,350	79	1	-	1	0	2	2	1
TF30-P-9	F-111D	1	307	[illegible]	5.1	54360	0.696	2 5	4.13		4070	20,840	12,430	80	2	2	1	0	2	2	1
TF30-P-100	F-111F	1	343	[illegible]515	5.3	65840	0.686	2 2	2.91		3999	25,100	14,560	84	2	2	1	0	2	2	1
TF33-P-3	B-52H	1	210	2060	4.4	19240	0.520	1.0	1.08		3905	17,000	16,500	51	1	-	1	0	2	2	1
TF33-P-5	C/WC-135B RC-135M/S	1	243	2060	4.2	19980	0.535	1.0	0.76		4275	18,000	16,400	106	1	-	1	0	2	2	1
TF33-P-7/7A	C-141A	1	243	2210	4.5	23680	0.530	1.0	0.51		4650	21,000	19,000	270	1	-	1	0	2	2	1
TF33-P-9	EC-135C RC-135C/U/V	1	243	2060	4.1	19980	0.530	1.0	0.55		4340	18,000	16,400	118	1	-	1	0	2	2	1
TF34-GE-100	A-10A	2	382	2720	6.4	16500	0.369	0.4	1.71		1427	9,065	7,990	107	2	2	1	0	2	1	1
TF39-GE-1A	C-5A	2	322	2810	5.5	19500	0.315	1.0	0.98		7475	40,805	40,805	162	1	-	1	0	2	[illegible]	1
TF41-A-1/1A	A-7D	1	316	2625	4.6	28770	0.647	0.9	7.90		3175	14,500	14,500	158	2	2	[illegible]	26	2	-	1
F100-PW-100	F-15A	2	370	3025	7 9	65000	0.720	2.3	9.57		3021	23,840	14,690	109	2	1	1	0	[illegible]	2	[illegible]
T56-A-7B	C/WC-130B C/DC/EC/WC-130E	2	179	2240	2 1*	6075	0.528*	1.0	0.64+		1833	3,755*	3,755*	nd	1	-	1	nd	-	-	1
T56-A-9B	C/AC/DC/RC-130A C-130D	2		2240	2 1*	5850	0.540*	1.0	1.21+		1679	3,460*	3,460*	nd	1	-	1	nd	-	-	1
T56-A-15	C/AC/DC/HC/WC-130H HC-130N/P	2	254	2430	2.4*	6140	0.507*	0.8	0.69+		1844	4,368*	4,368*	nd	1	-	1	nd	-	-	1
T76-GE-10A	OV-10A	2	292	2278	2.1*	1763	0 600*	0.3	1.75		335	715*	715*	180	1	-	1	[illegible]	-	1	[illegible]
T76-GE-12A	OV-10A	2	291	2278	2.1*	1763	0.600*	0.3	1.61		330	715*	715*	190	1	-	[illegible]	1	-	1	[illegible]

[a] 1 = OC, 2 = SA.
[b] 1 = bomber/cargo; 2 = fighter/attack/trainer
[c] 1 = air-to-air, 2 = air-to-ground.
[d] 1 = multiengine, 2 = single-engine.
[e] 1 = no, 2 = yes.
[f] 1 = GE, 2 = P&W.
[g] 1 = organic; 2 = contract.

- = not applicable.
* Based on equivalent shaft horsepower
+ Engine only (gearbox excluded).
nd = not determined

Table D.3

AVIONICS EXPLANATORY VARIABLE VALUES

MDS	Size: Suite Weight (lbs.)	Performance/Complexity: Aircraft First Flight Date	Number of Black Boxes	Number of Functions	Suite Procurement Cost #1 ($)	Suite Procurement Cost #2 ($)	Mean Time Between OFM Demands (flying hours)	Mission DV (1=non-combat, 2=combat)	All-WX DV (1=no, 2=yes)	Mission Group DVs: Bomber	Cargo	Fighter/Attack	Recon	Trainer	Application: Annual FH per Aircraft	Annual Sorties per Aircraft	Peculiar Percentage: Based on $	Based on Item Count
A-7D	1,670	311	25	4	1,000,000[b]	1,063,000	3.20	2	2	1	1	2	1	1	259	140	61	56
A-10A	670	383[a]	18	2	445,000[b]			2	1	1	1	2	1	1	457	222		
A-37	230	287	11	2	22,000[c]			2	1	1	1	2	1	1	252	178		
B-52D		163	30	5	3,507,000[c]	4,373,000	0.93	2	2	2	1	1	1	1	357	47	10	8
B-52G		189	33	5	3,242,000[c]	7,923,000	0.84	2	2	2	1	1	1	1	427	54	7	2
B-52H	6,200	218	29	5	3,363,000[c]	10,410,000	0.94	2	2	2	1	1	1	1	429	52	30	7
C-5A	2,640	305	34	3	1,912,000[b]	5,497,000	2.67	1	2	1	2	1	1	1	683	140	99	87
C-130E		223	25	3				1	2	1	2	1	1	1	606	212		
C-141A	1,400	191	24	3	803,000[b]	1,223,000	3.08	1	2	1	2	1	1	1	1,120	304	32	20
F-4C	2,210	184	12	4	930,000[b]	1,127,000	1.44	2	2	1	1	2	1	1	231	147	50	21
F-4D	2,340	269	14	4	1,190,000[b]	2,260,000	1.54	2	2	1	1	2	1	1	239	150	59	17
F-4E	1,780	294	13	4	1,059,000[b]	1,753,000	1.64	2	2	1	1	2	1	1	256	168	49	41
F-5B		254	5	2	90,000[c]			2	1	1	1	2	1	1	362	272		
F-5E	343	355	9	3	135,000[b]			2	1	1	1	2	1	1	238	218		
F-15A	2,184	354	26	5	2,750,000[c]			2	2	1	1	2	1	1	223	156		
F-101B	1,268	170	7	2	486,000[d]			2	2	1	1	2	1	1	239	115		
F-105B	654	173	11	3	634,000[d]			2	2	1	1	2	1	1	236	146		
F-105D		197	11	3	880,000[d]			2	2	1	1	2	1	1	219	135		
F-105F		246	10	3	713,000[c]			2	2	1	1	2	1	1	206	138		
F-105G		353	13	3	744,000[c]			2	2	1	1	2	1	1	210	129		
F-106A		167	24	3	285,000[c]			2	2	1	1	2	1	1	309	174		
F-106B		183			293,000[c]			2	2	1	1	2	1	1	312	252		
F-111A	1,921	263	20	5	1,764,000[b]	6,347,000	1.19	2	2	1	1	2	1	1	189	71	32	18
F-111D	2,752	310	24	5	3,705,000[b]	7,803,000	0.75	2	2	1	1	2	1	1	200	67	69	36
F-111E	2,592	319	18	5	2,227,000[b]			2	2	1	1	2	1	1	253	85		
F-111F	2,475	343	21	5	2,230,000[b]	3,110,000	1.55	2	2	1	1	2	1	1	254	85	17	8
T-33A		62	13	3	21,000[c]			1	1	1	1	1	1	2	284	185		
T-37B		197	6	2	111,000[c]	150,000	11.33	1	1	1	1	1	1	2	459	342	1	1
T-38A		204	9	2	18,000[c]	220,000	13.72	1	1	1	1	1	1	2	402	315	1	2
T-39A		210	11	2	26,000[c]			1	1	1	1	1	1	2	935	534		
FB-111A	2,921	294	21	5	2,870,000[b]			2	2	2	1	1	1	1	265	70		
KC-135A		163	22	3		1,325,000	1.88	1	2	1	2	1	1	1	325	68	5	10
OV-10A		270	10	2	186,000[c]			2	1	1	1	1	2	1	326	180		
RF-4C		255	22	6		7,287,000	1.16	2	2	1	1	1	2	1	266	145	67	56
TF-15A		366	26	5	2,519,000[c]			1	2	1	1	1	1	2	247	126		

[a] RDT&E aircraft

[b] WD-258-AF

[c] Estimate by J. Dryden

[d] RM-4851-PR

Appendix E

DATA PLOTS

Appendix E

DATA PLOTS

Figure	Dependent Variable	Independent Variable
E.1	Total airframe rework cost	Inventory (PDM Policy)
E.2	Total airframe rework cost	Production quantity
E.3	Total airframe rework cost	Fleet flying hours (PDM Policy)
E.4	Production quantity	Age
E.5	Production quantity	Percent organic maintenance
E.6	Airframe rework cost per acft	Empty weight (PDM Policy)
E.7	Airframe rework cost per acft	Airframe manufacturing cost
E.8	Airframe rework cost per acft	Production quantity
E.9	Airframe rework cost per visit	Age
E.10	Airframe rework cost per visit	Airframe manufacturing cost
E.11	Airframe rework cost per visit	Percent organic maintenance
E.12	Airframe rework cost per visit	Production quantity
E.13	Average time between overhauls	Turbine inlet temperature
E.14	Average time between overhauls	Engine removal rate
E.15	Average time between overhauls	Selling price
E.16	Average time between overhauls	Specific fuel consumption
E.17	Average time between overhauls	Engine weight
E.18	Average time between overhauls	Model qualification date
E.19	Engine overhaul cost	Turbine inlet temperature
E.20	Engine overhaul cost	Specific fuel consumption
E.21	Engine overhaul cost	Selling price
E.22	Engine overhaul cost	Engine weight
E.23	Engine overhaul cost	Military thrust
E.24	Engine overhaul cost	Model qualification date
E.25	Engine cost to repair	Turbine inlet temperature
E.26	Engine cost to repair	Specific fuel consumption
E.27	Engine cost to repair	Selling price
E.28	Engine cost to repair	Engine weight
E.29	Engine cost to repair	Maximum thrust
E.30	Engine cost to repair	Military thrust
E.31	Engine cost to repair	Model qualification date

Figure	Dependent Variable	Independent Variable
E.32	Airframe component repair cost	Airframe manufacturing cost
E.33	Airframe component repair cost	Airframe manufacturing cost (PDM Policy)
E.34	Airframe component repair cost	Empty weight (PDM Policy)
E.35	Airframe component repair cost	Empty weight (afterburner)
E.36	Airframe component repair cost	Sortie rate
E.37	Engine component and accessory repair cost	Turbine inlet temperature
E.38	Engine component and accessory repair cost	Specific fuel consumption
E.39	Engine component and accessory repair cost	Selling price
E.40	Engine component and accessory repair cost	Engine weight
E.41	Engine component and accessory repair cost	Maximum thrust
E.42	Engine component and accessory repair cost	Military thrust
E.43	Engine component and accessory repair cost	Model qualification date
E.44	Avionics component repair cost	Black box count
E.45	Avionics component repair cost	Suite weight
E.46	Avionics component repair cost	Suite functions
E.47	Avionics component repair cost	Mean time between demands
E.48	Avionics component repair cost	Sortie rate
E.49	Avionics component repair cost	Percent peculiar cost
E.50	Avionics component repair cost	All-weather variable
E.51	Avionics component repair cost	First flight date

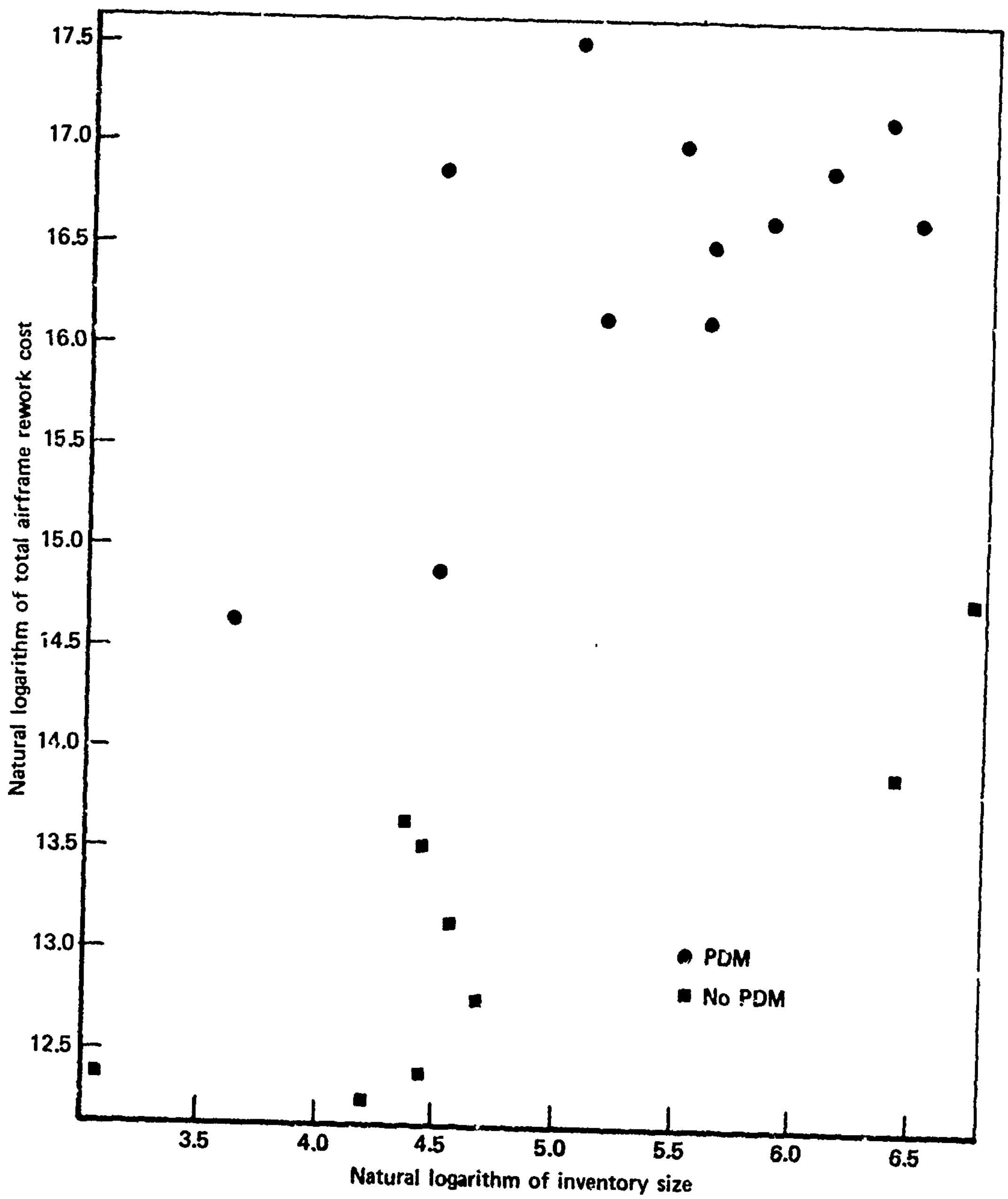

Fig. E.1—Variation of total airframe rework cost with inventory size

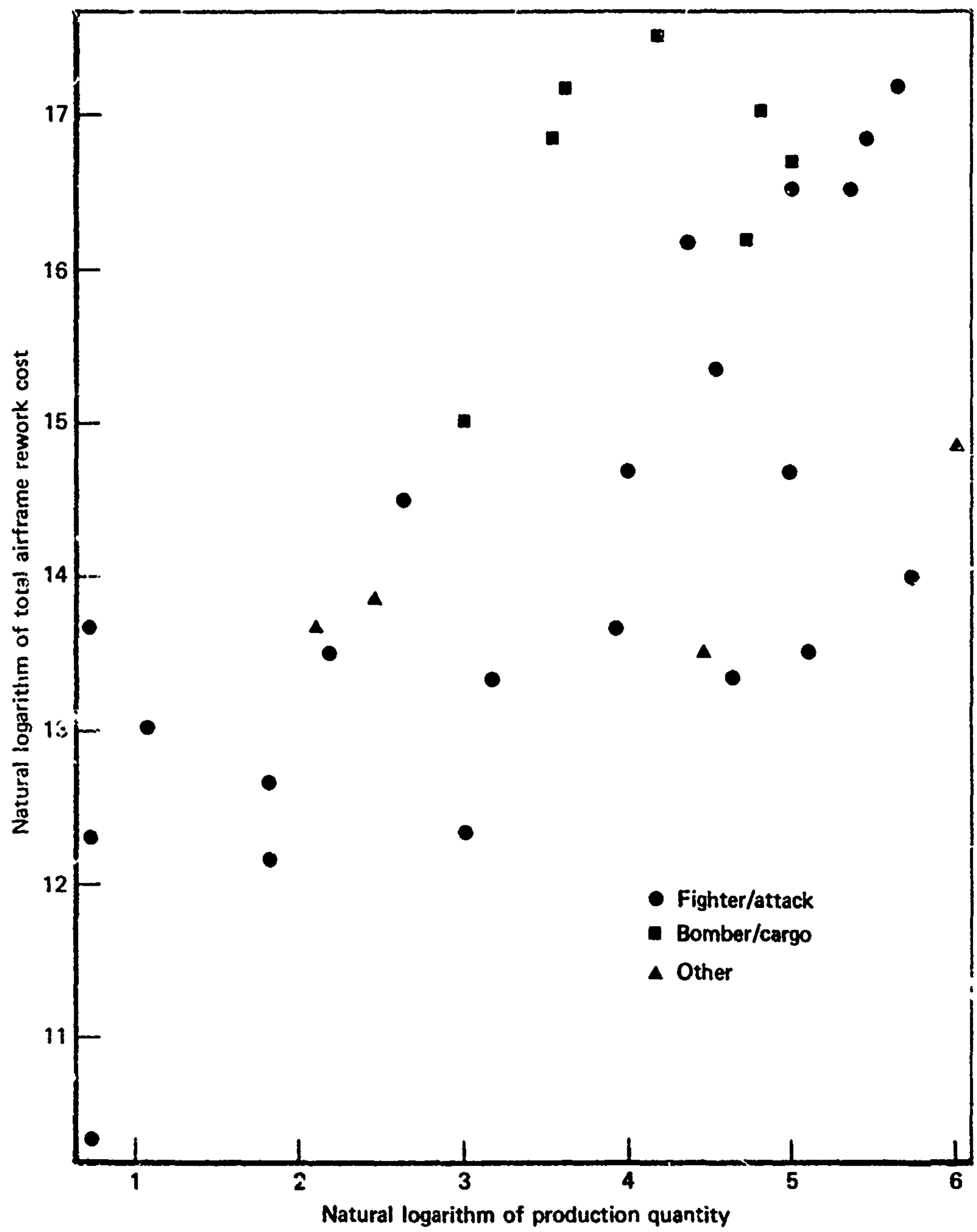

Fig. E.2—Variation of total airframe rework cost with production quantity

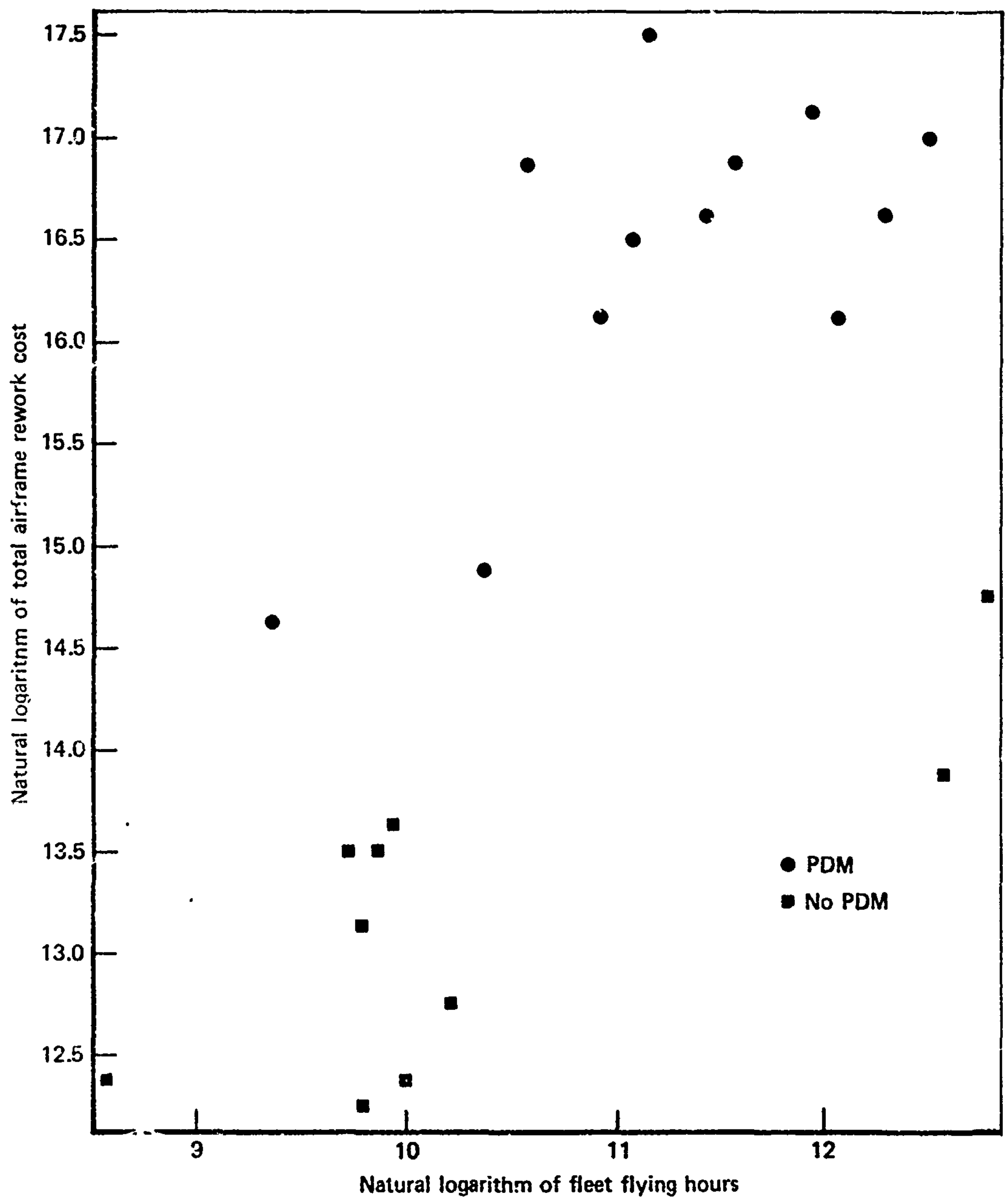

Fig. E.3—Variation of total airframe rework cost with fleet flying hours and PDM policy

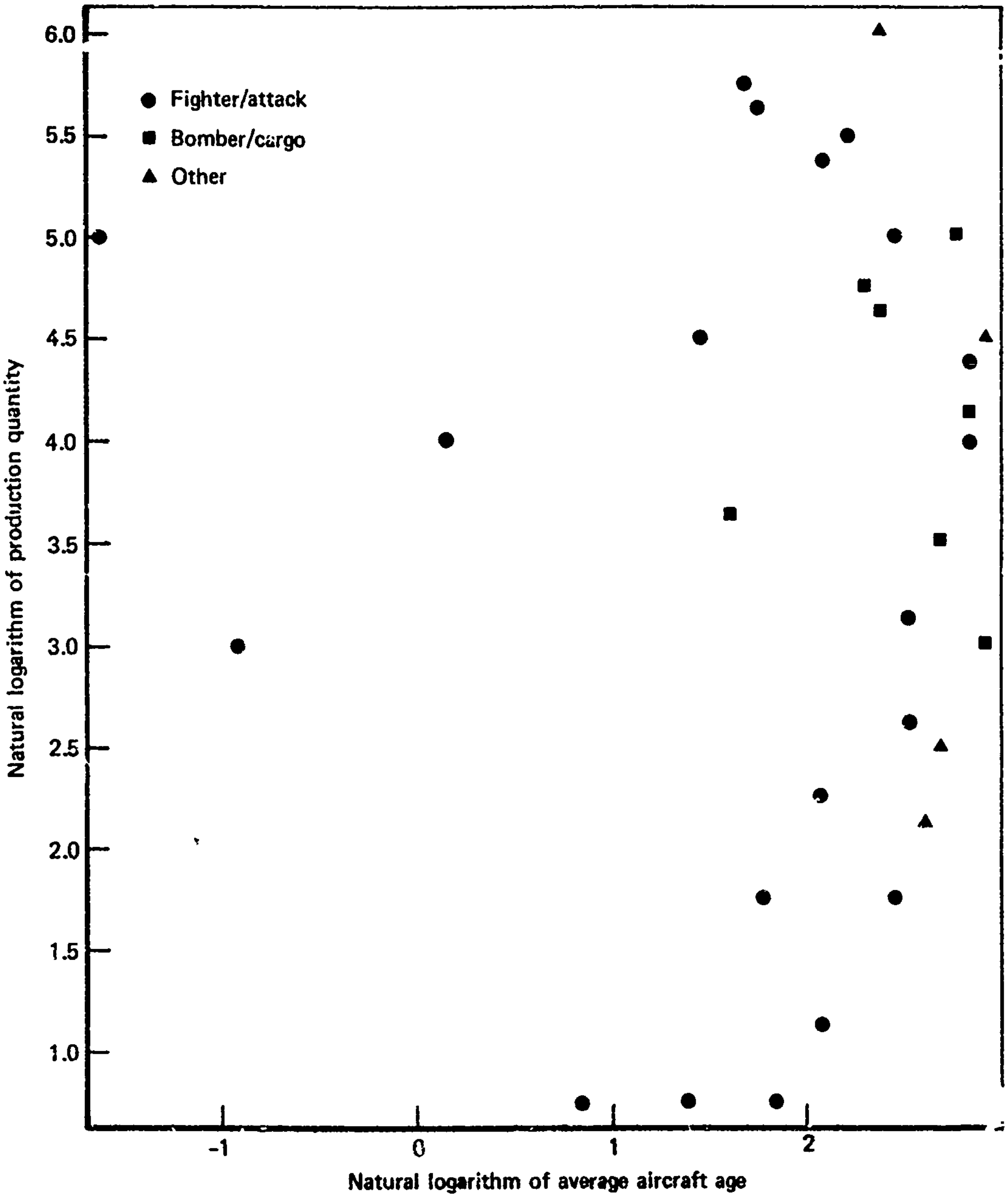

Fig. E.4—Variation of production quantity with age

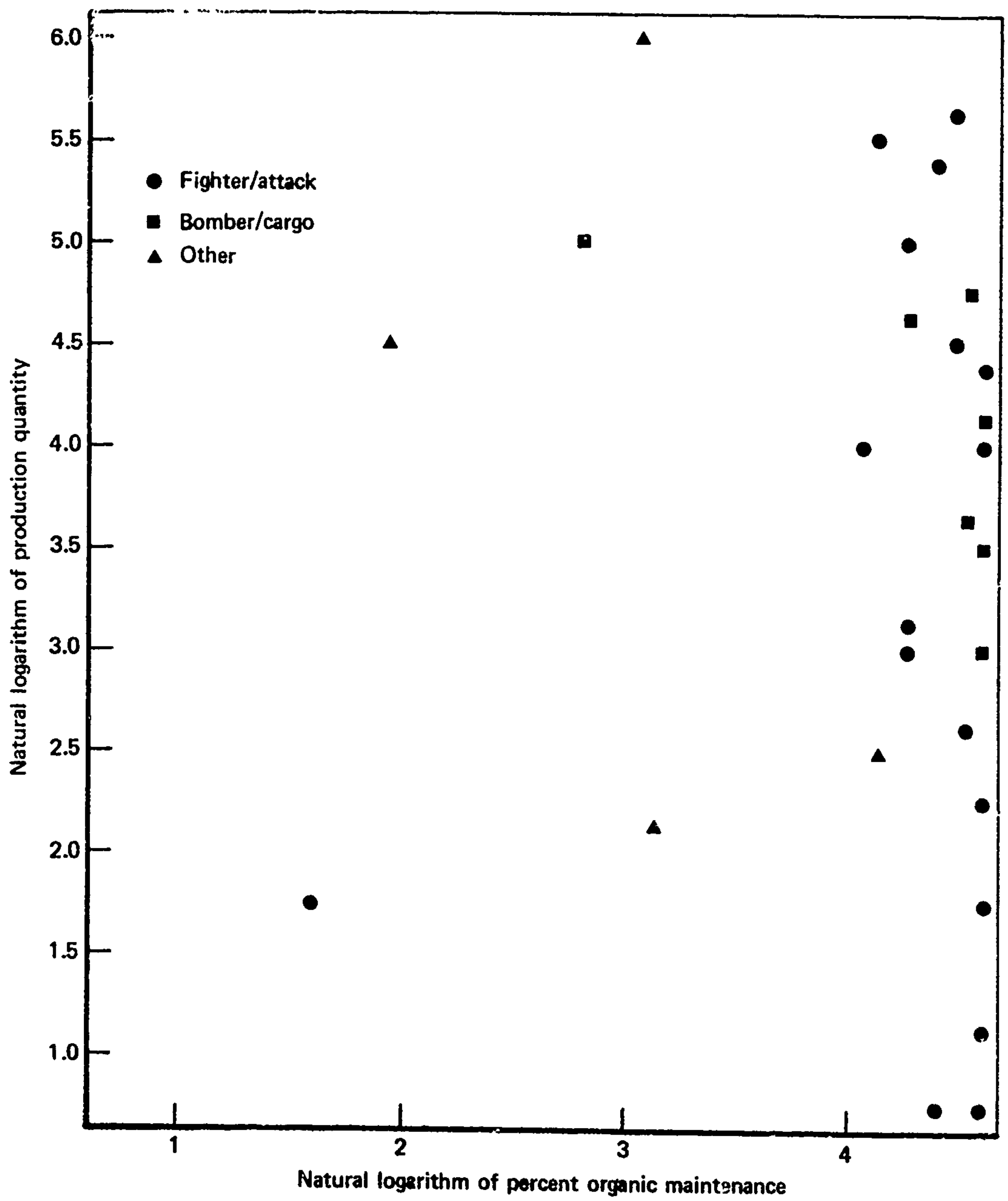

Fig. E.5—Variation of production quantity with percent organic maintenance

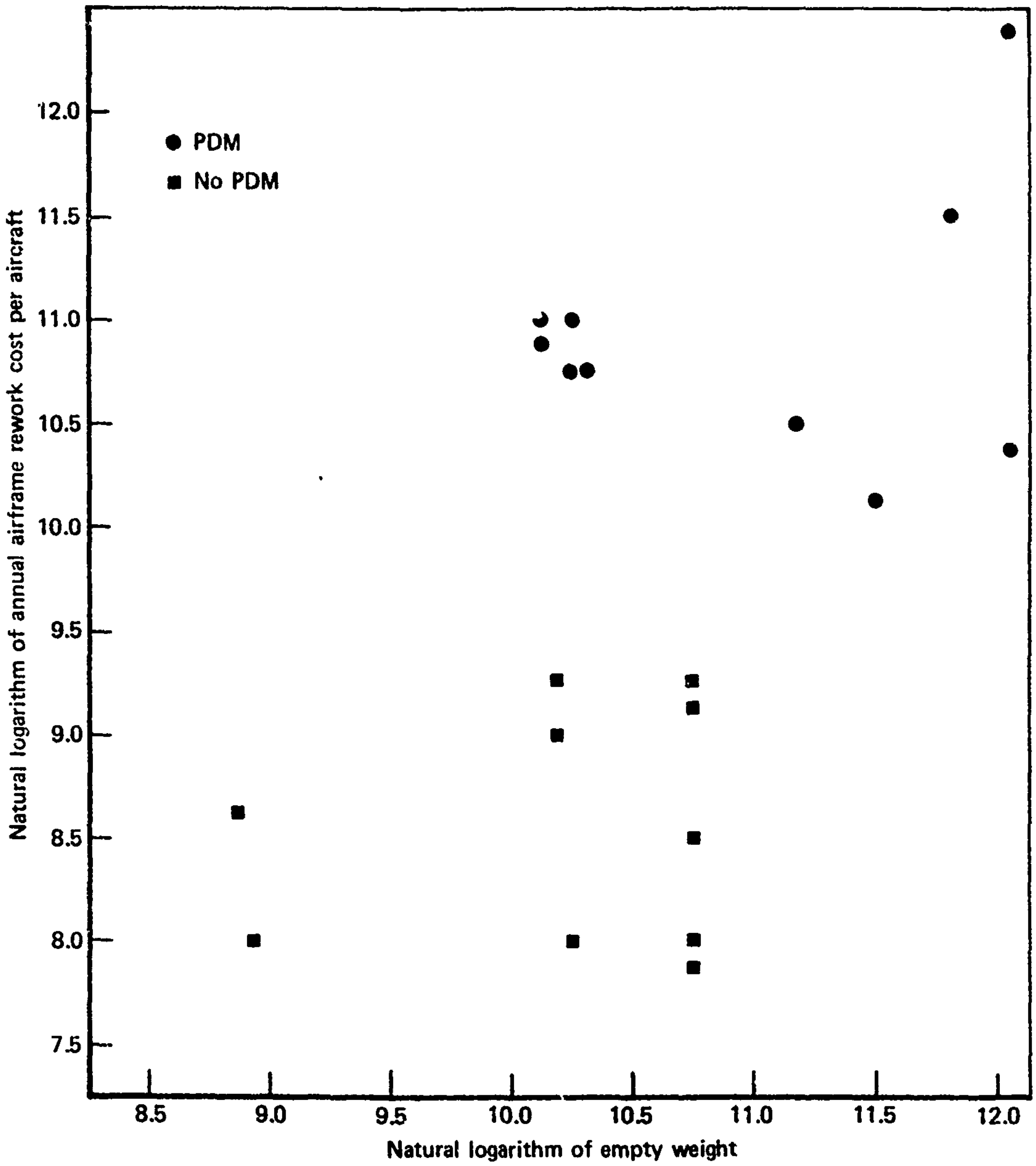

Fig. E.6—Variation of annual airframe rework cost per aircraft with empty weight and PDM policy

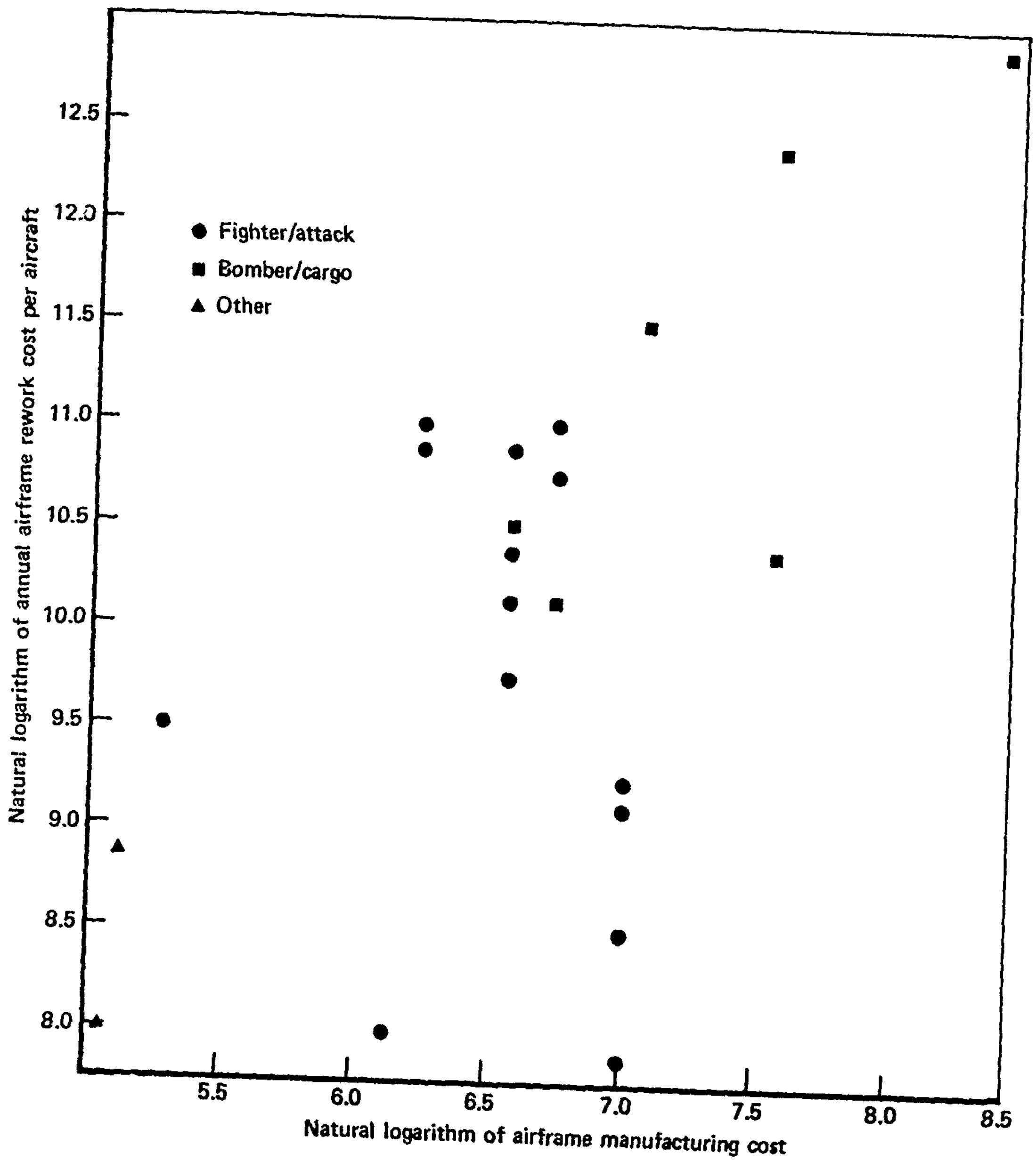

Fig. E.7—Variation of annual airframe rework cost per aircraft with airframe manufacturing cost

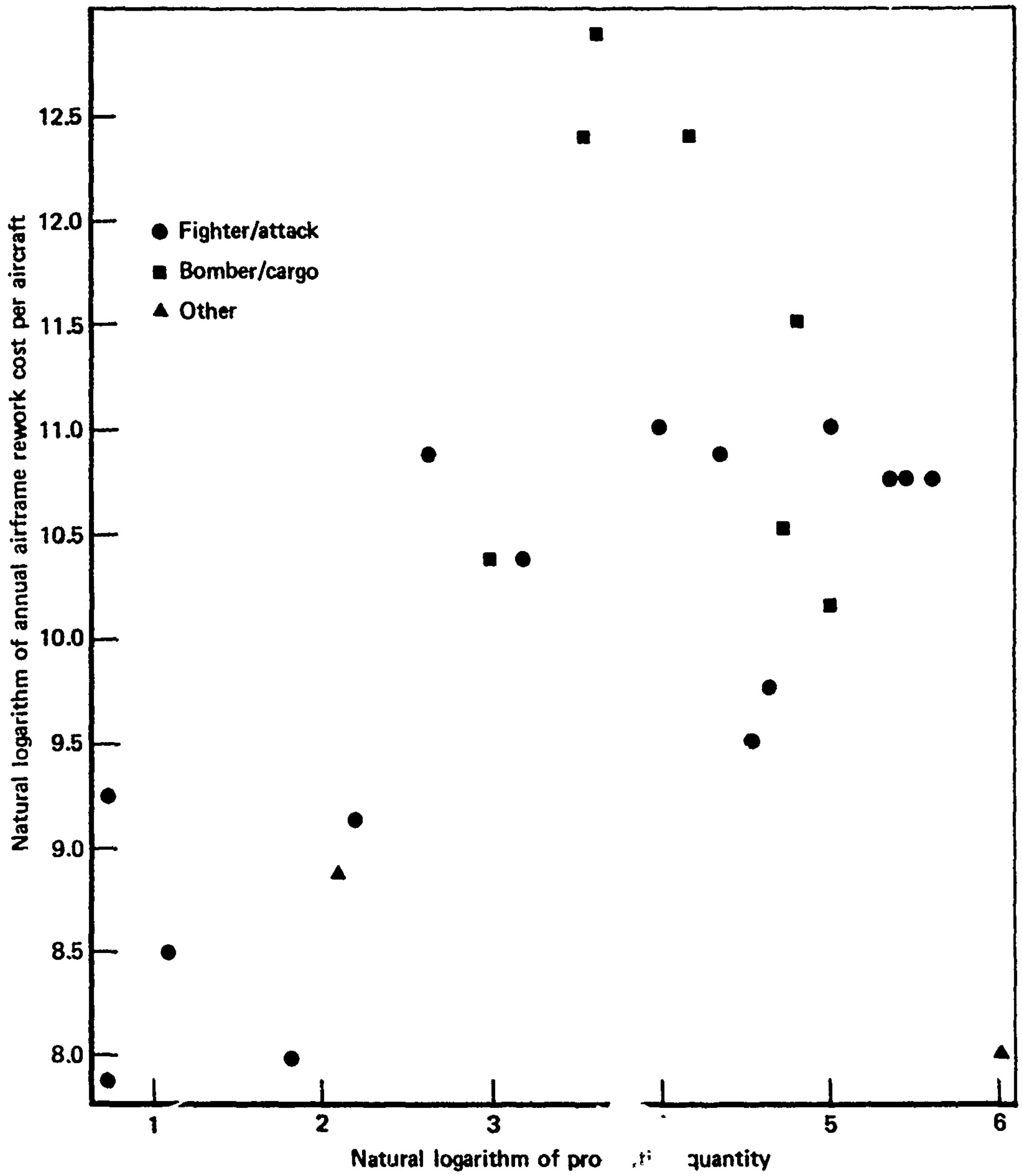

Fig. E.8—Variation of annual airframe rework cost per aircraft with production quantity

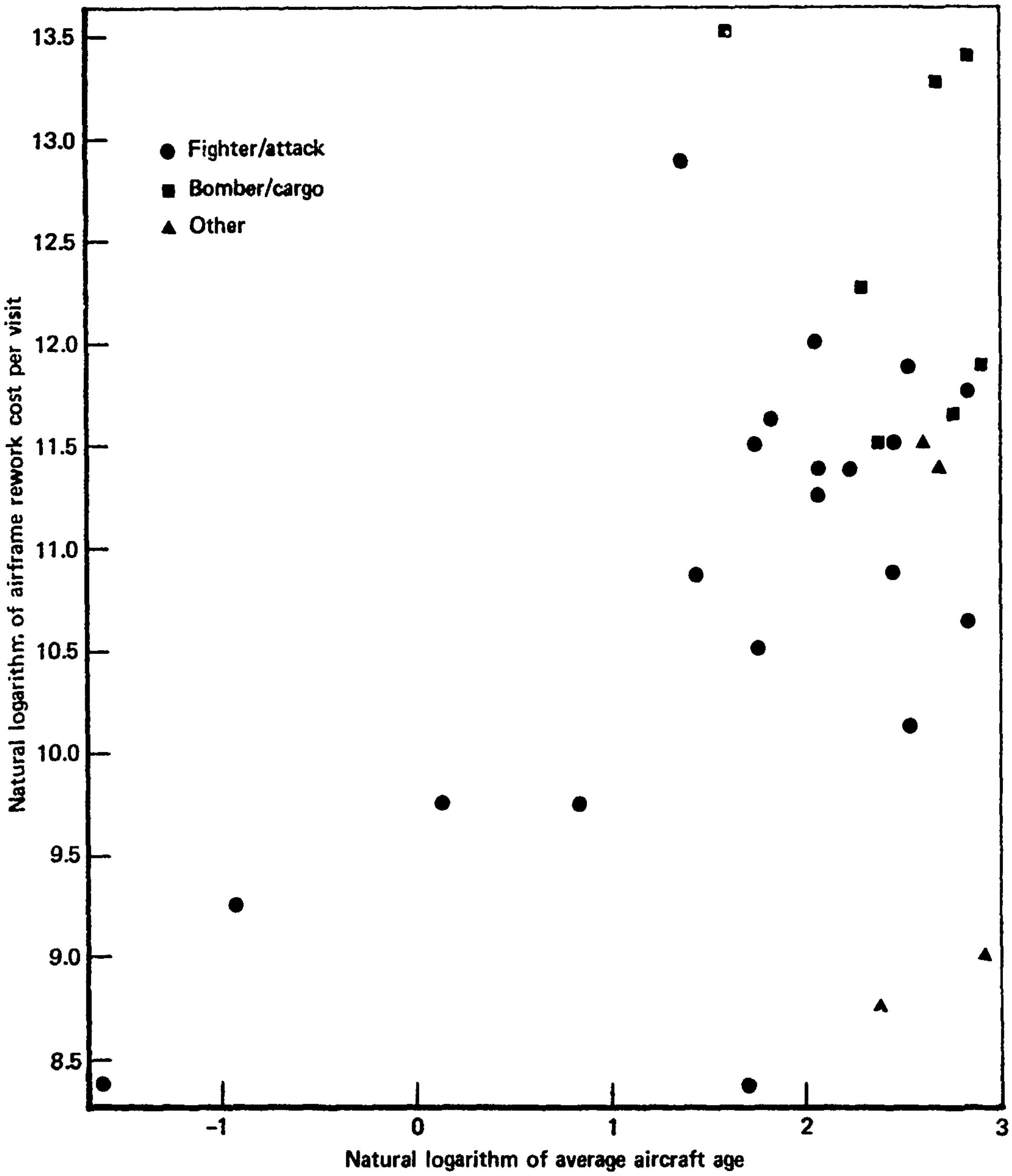

Fig. E.9—Variation of airframe rework cost per visit with age

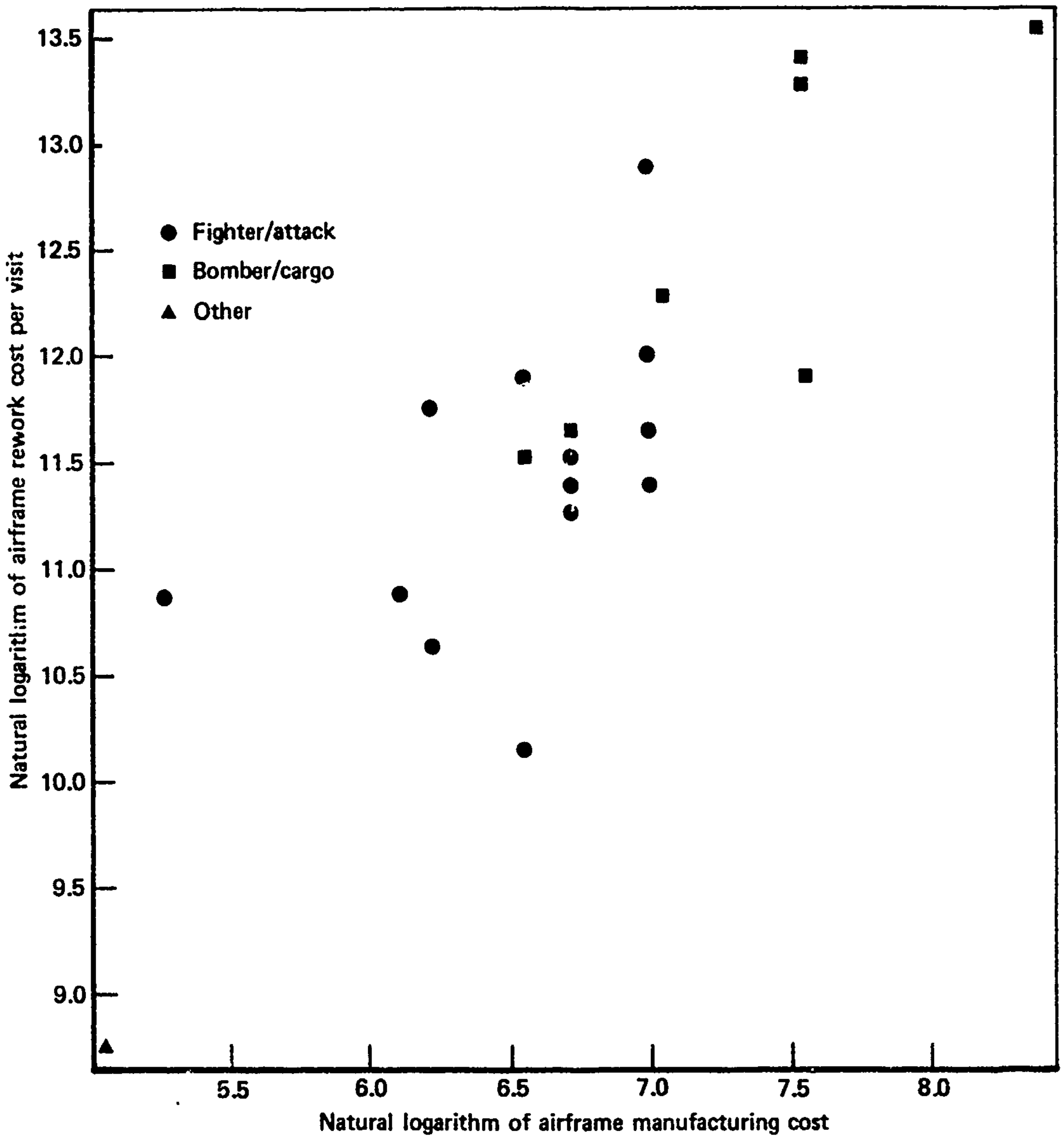

Fig. E.10—Variation of airframe rework cost per visit with airframe manufacturing cost

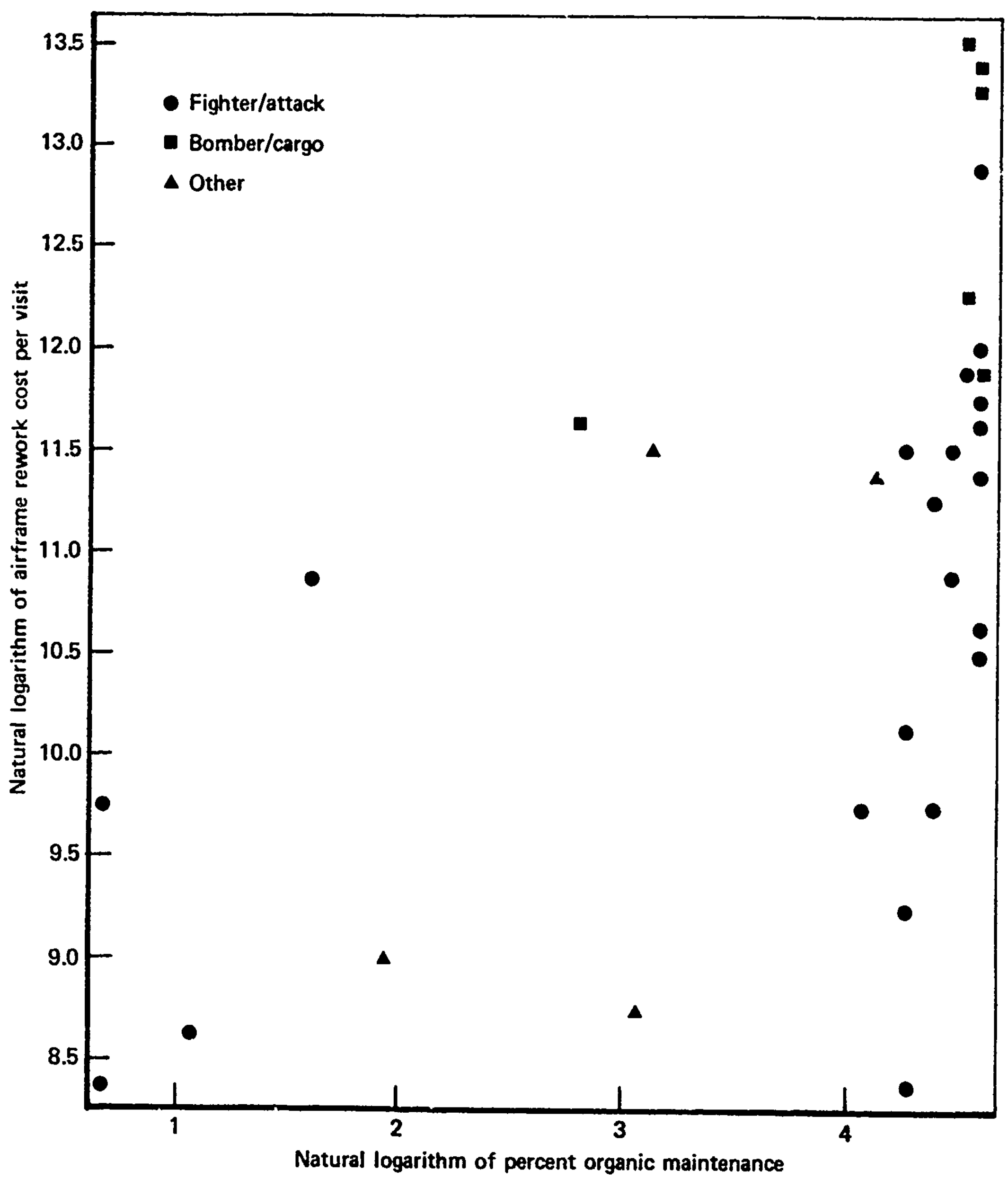

Fig. E.11—Variation of airframe rework cost per visit with percent organic maintenance

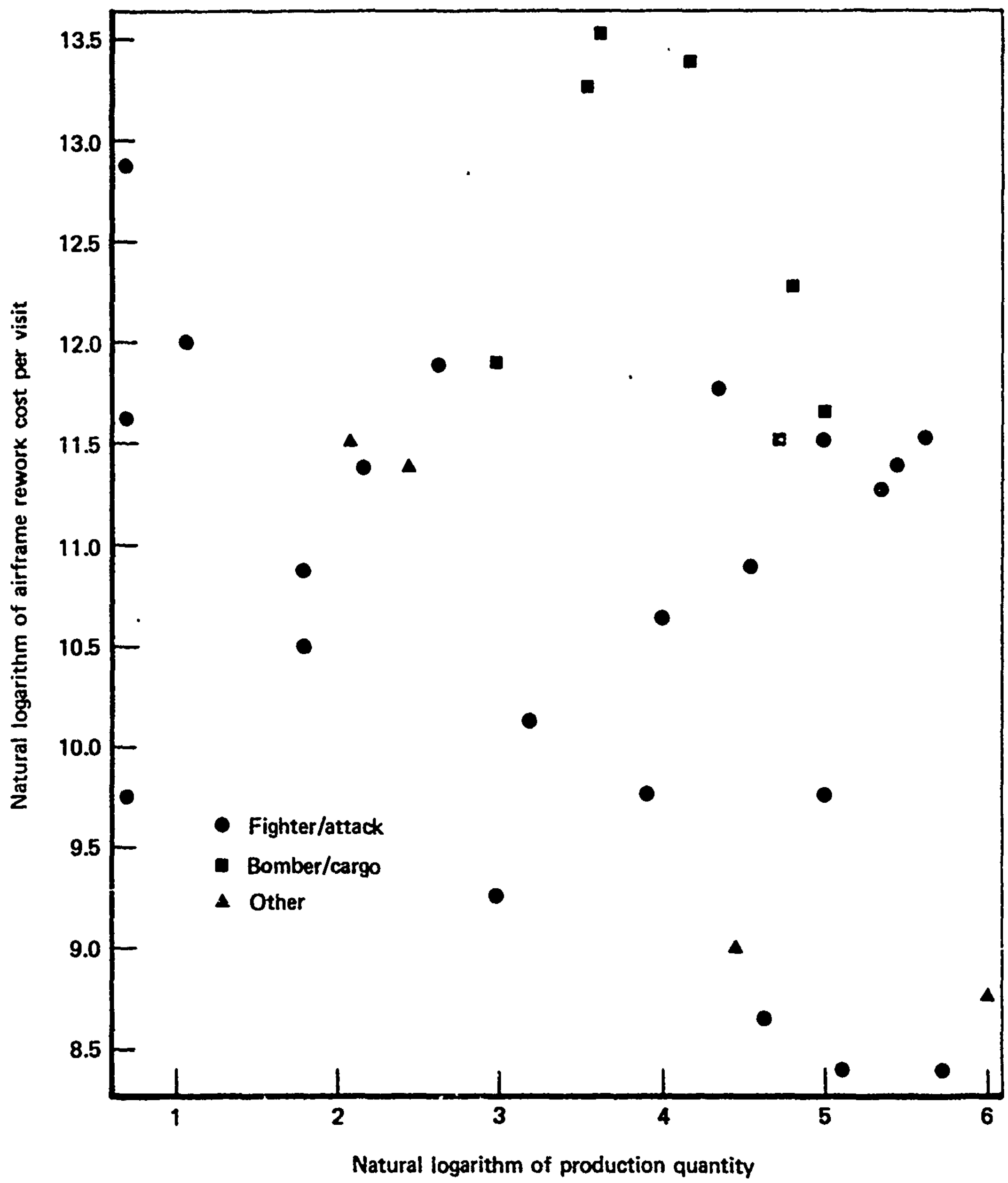

Fig. E.12—Variation of airframe rework cost per visit with production quantity

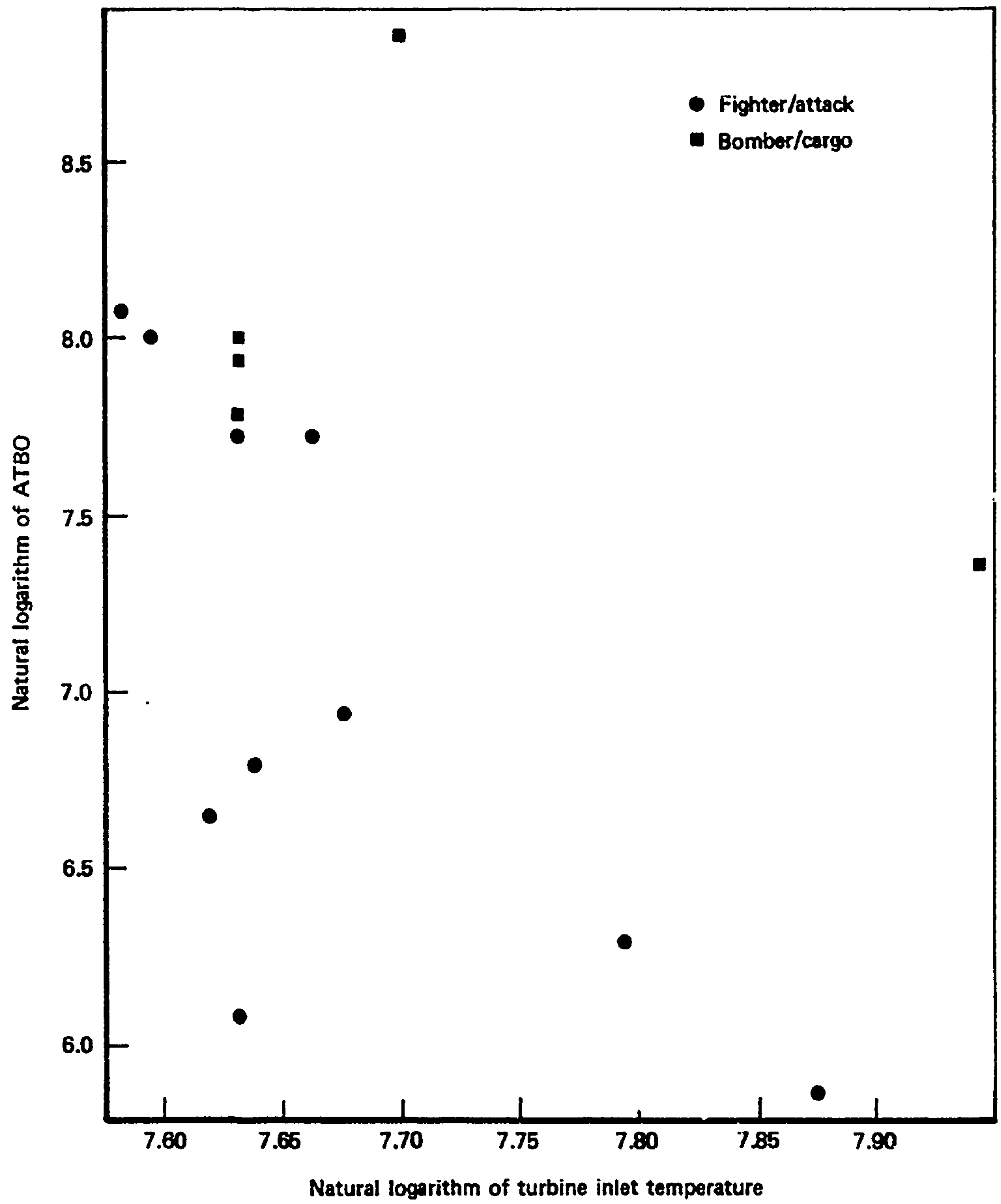

Fig. E.13—Variation of ATBO with turbine inlet temperature

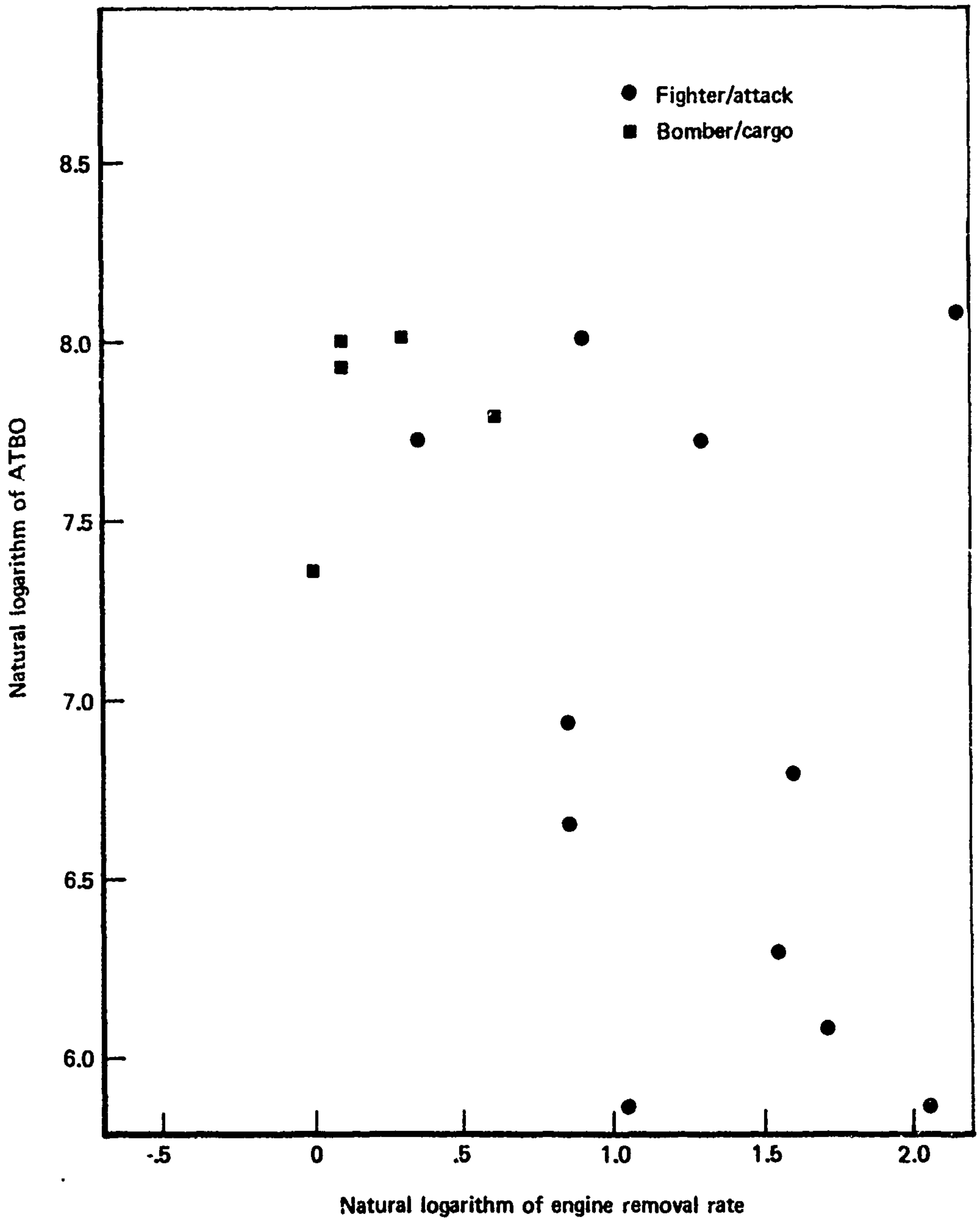

Fig. E.14—Variation of ATBO with engine base-level removal rate

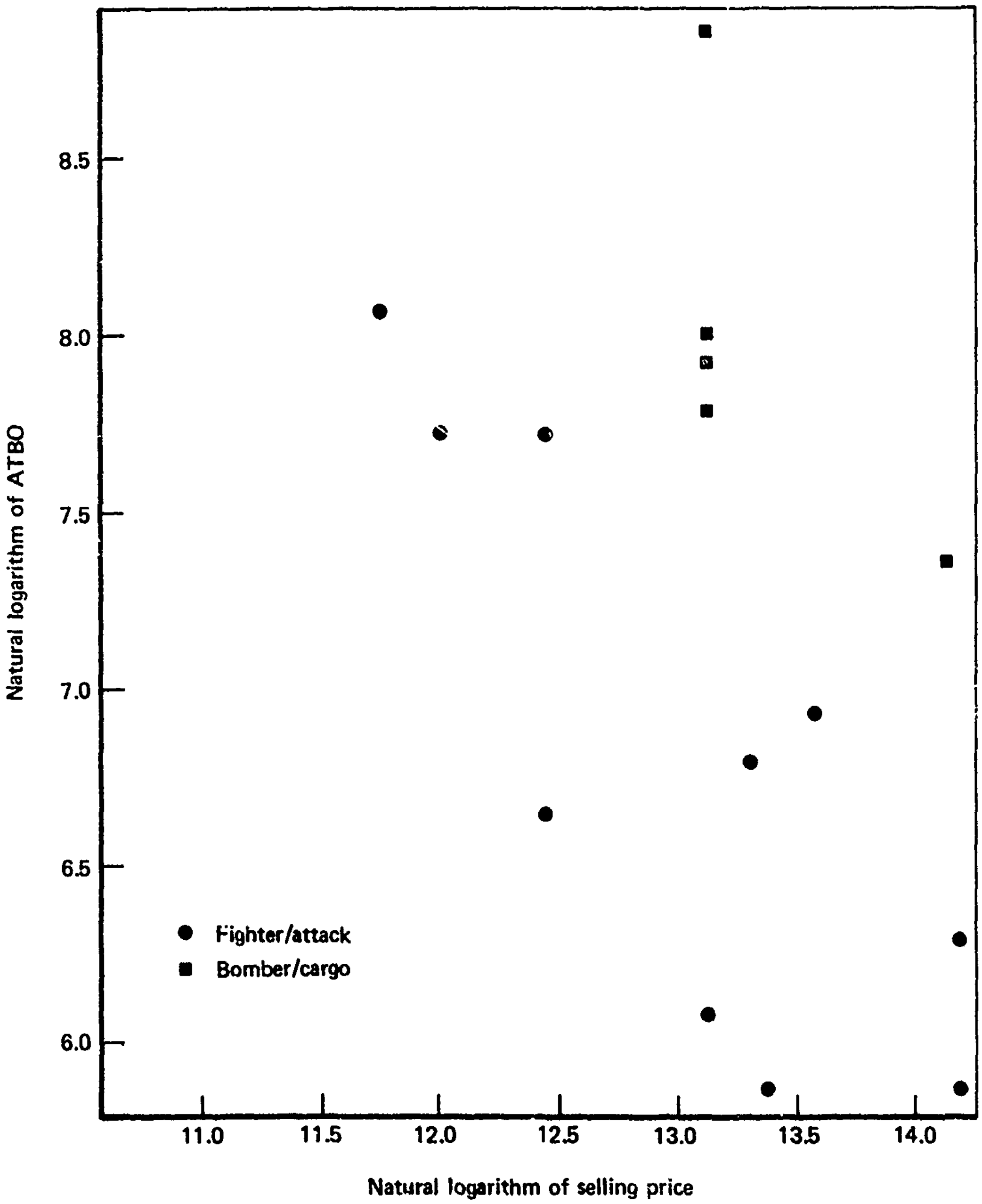

Fig. E.15—Variation of ATBO with selling price

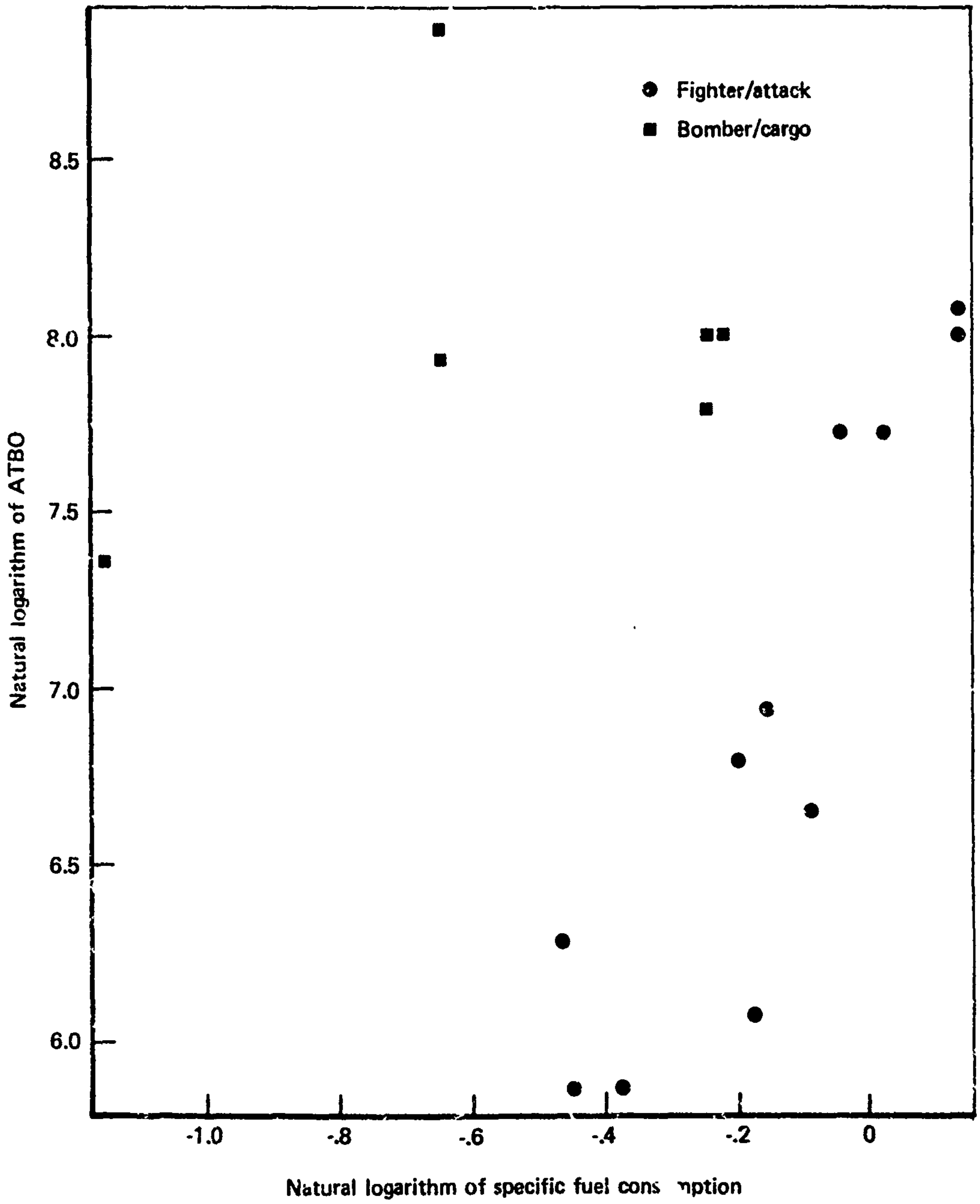

Fig. E.16—Variation of ATBO with specific fuel consumption

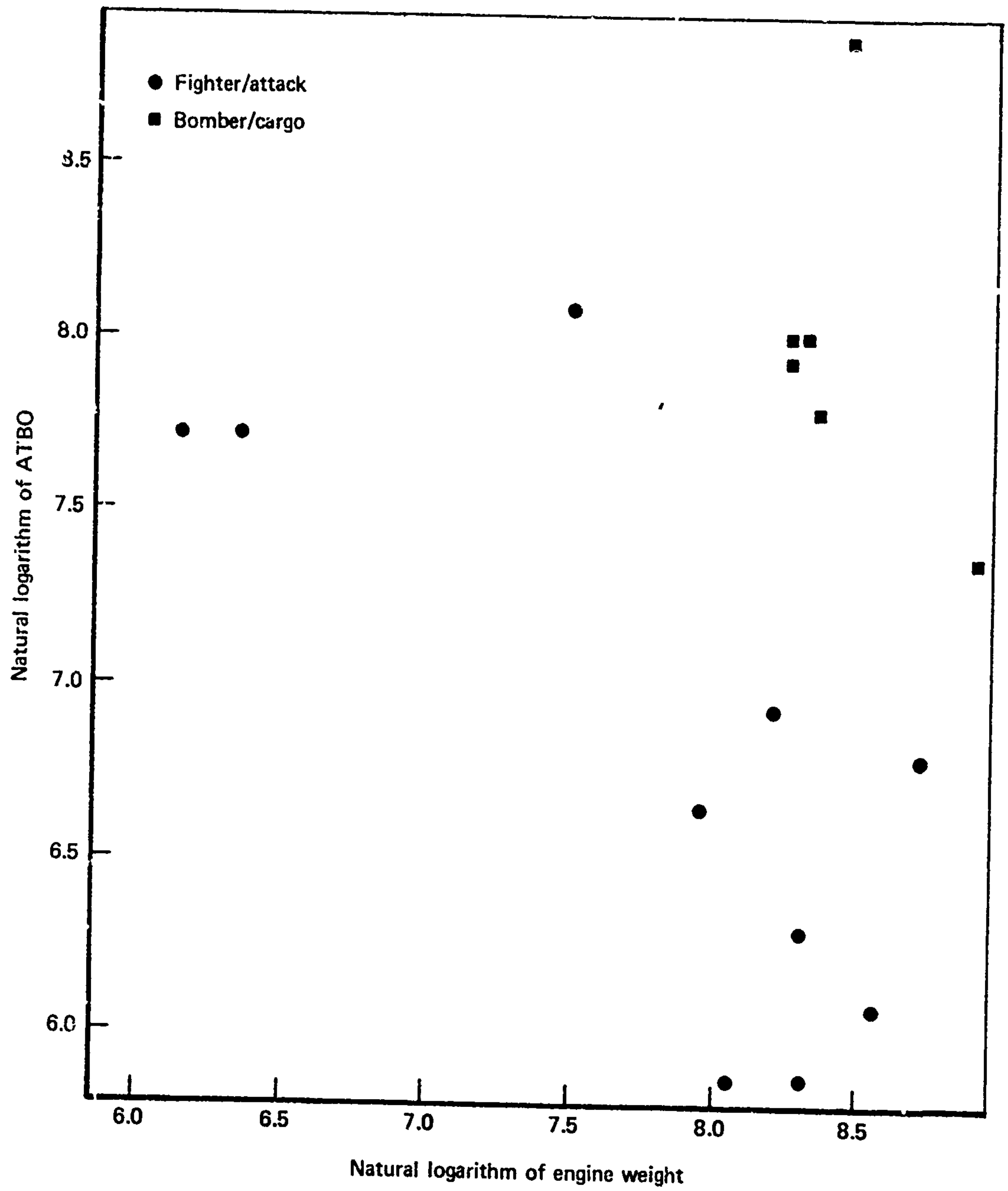

Fig. E.17—Variation of ATBO with engine weight

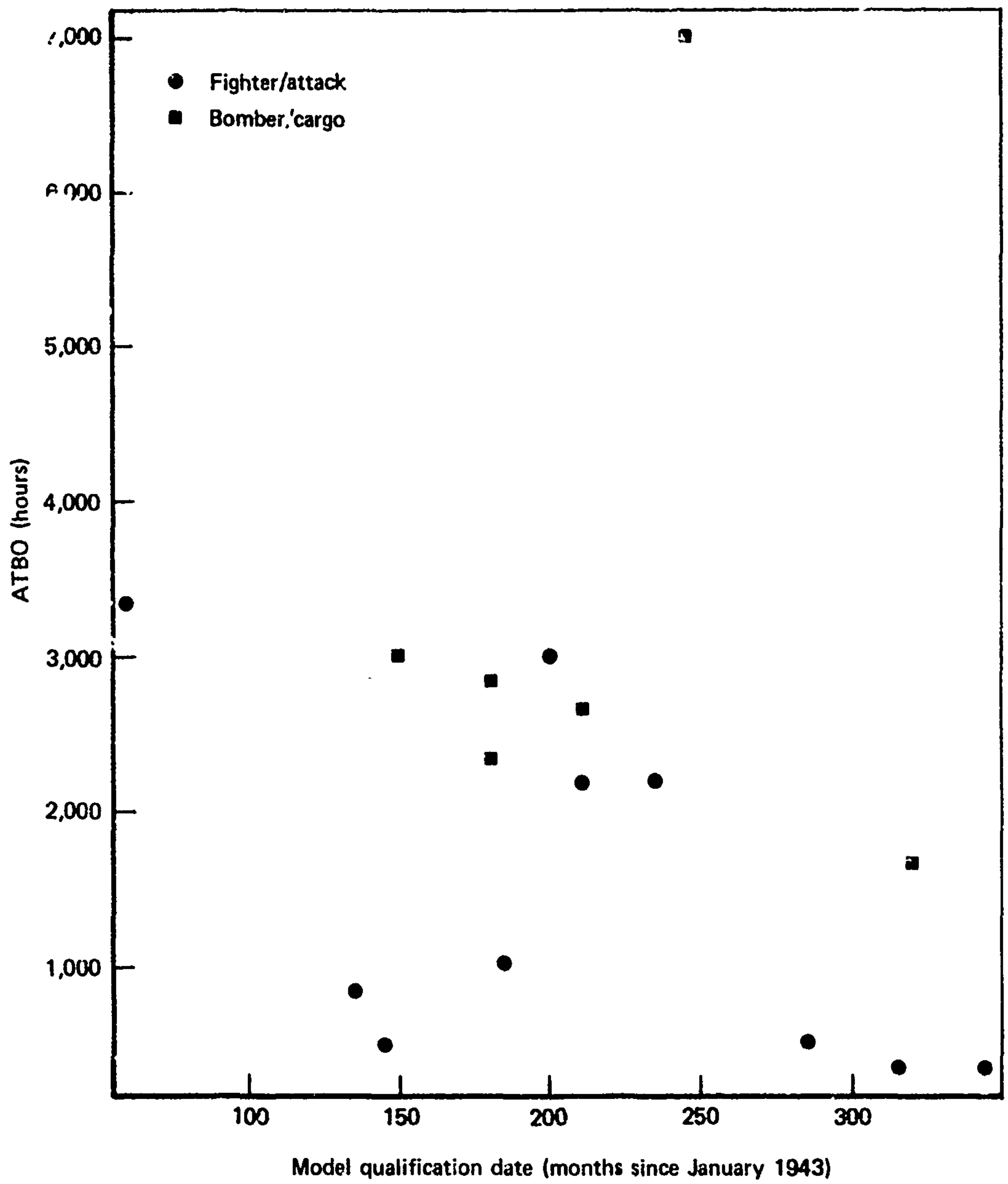

Fig. E.18—Variation of ATBO with model qualification date

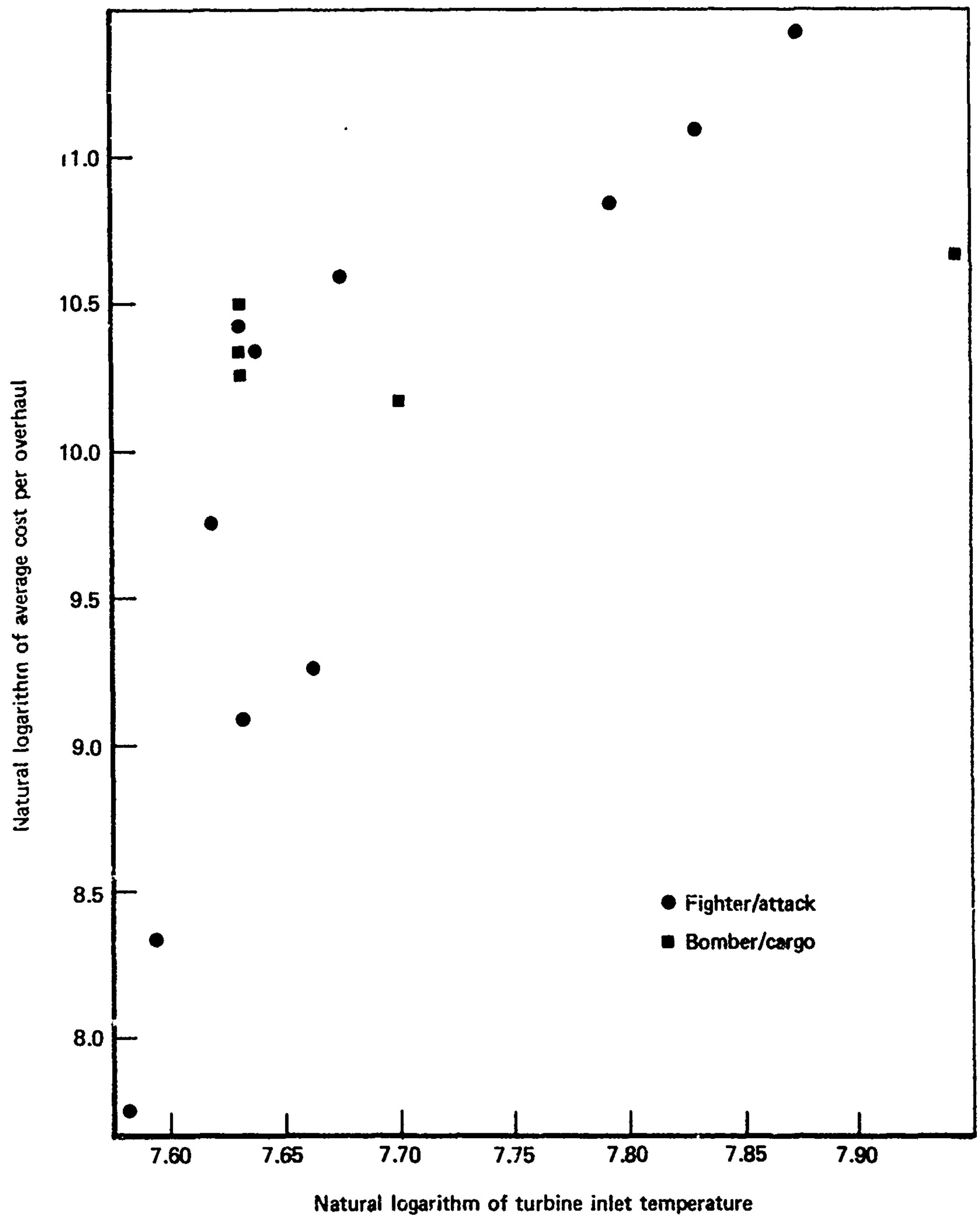

Fig. E.19—Variation of overhaul cost with turbine inlet temperature

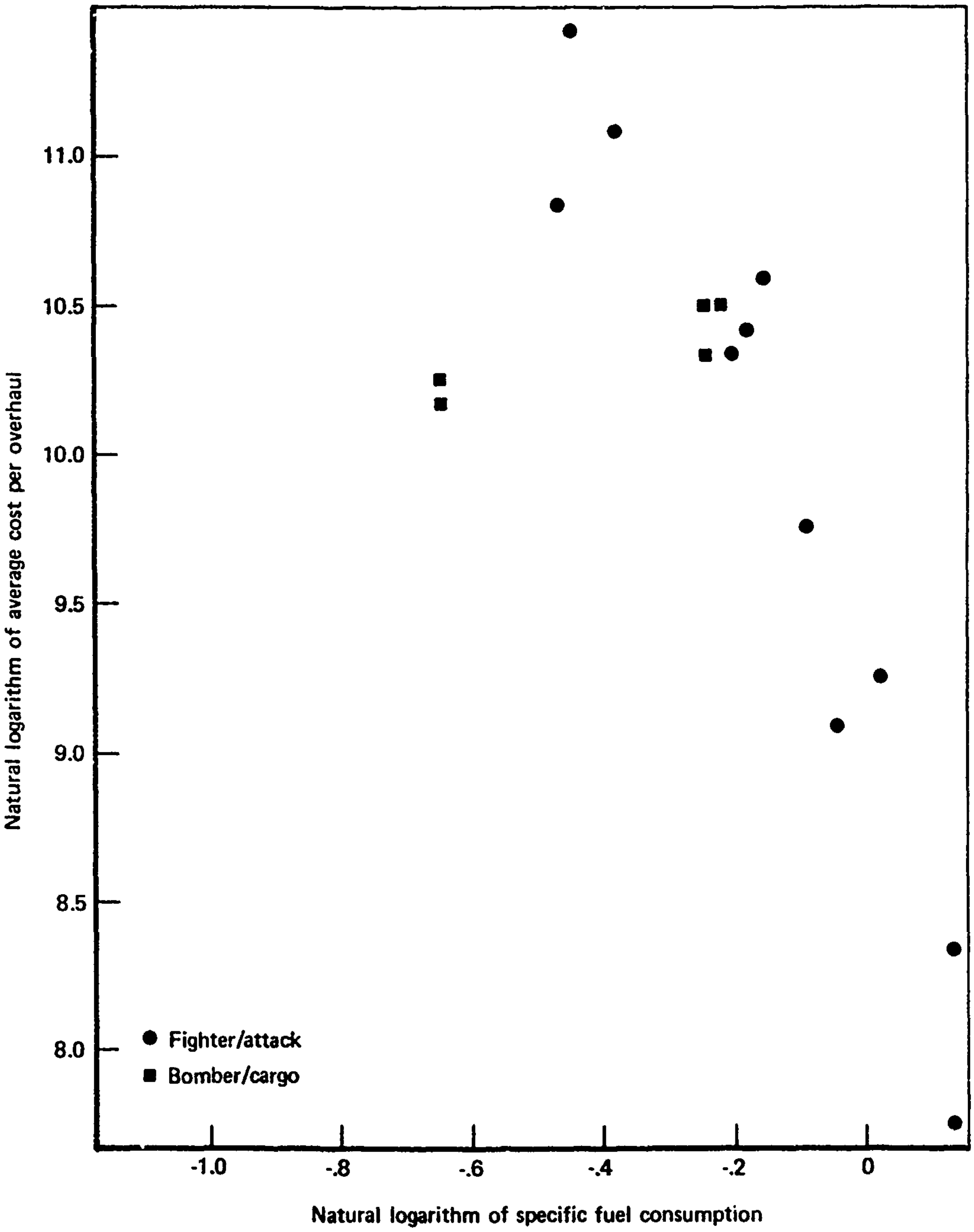

Fig. E.20—Variation of overhaul cost with specific fuel consumption

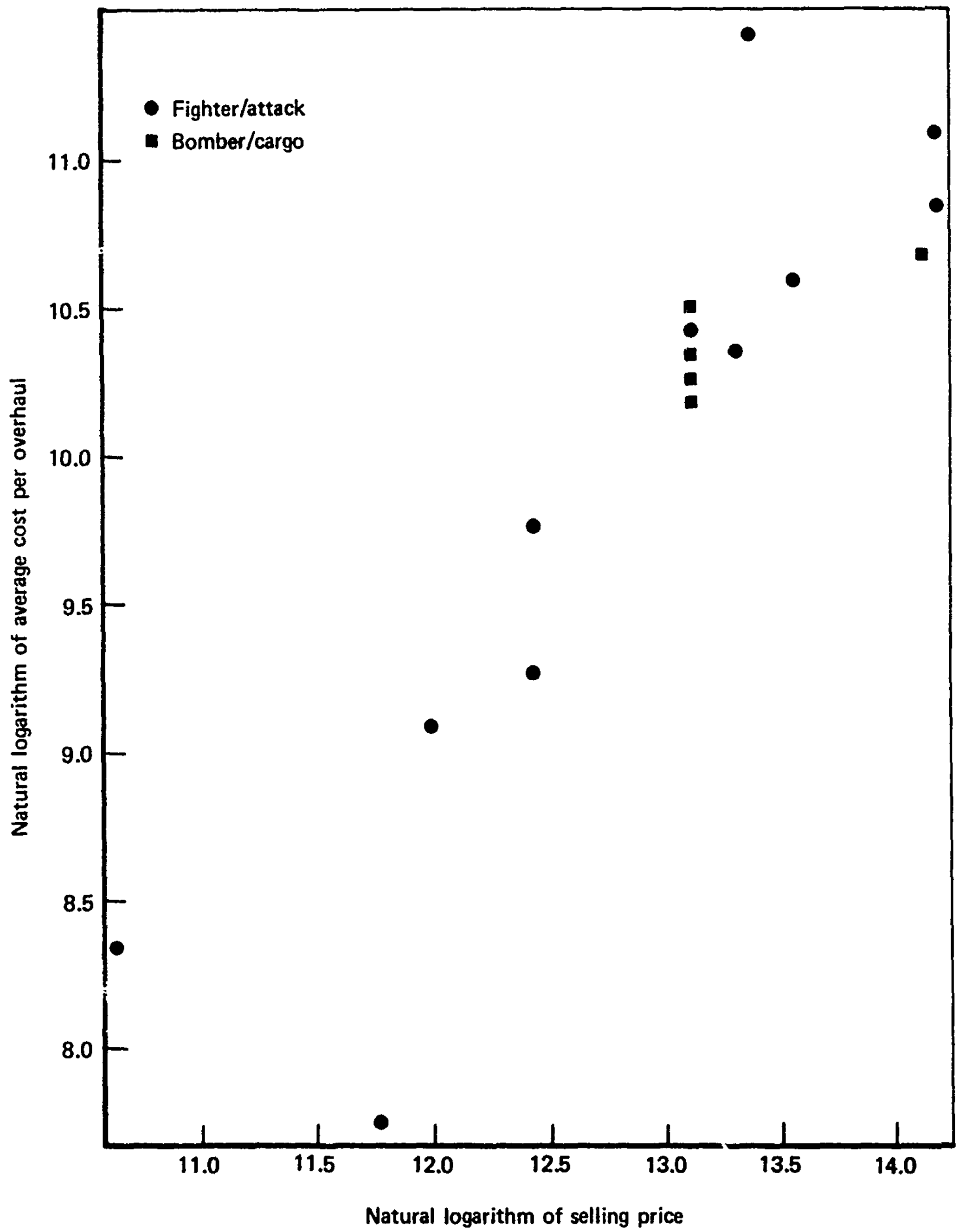

Fig. E.21—Variation of overhaul cost with selling price

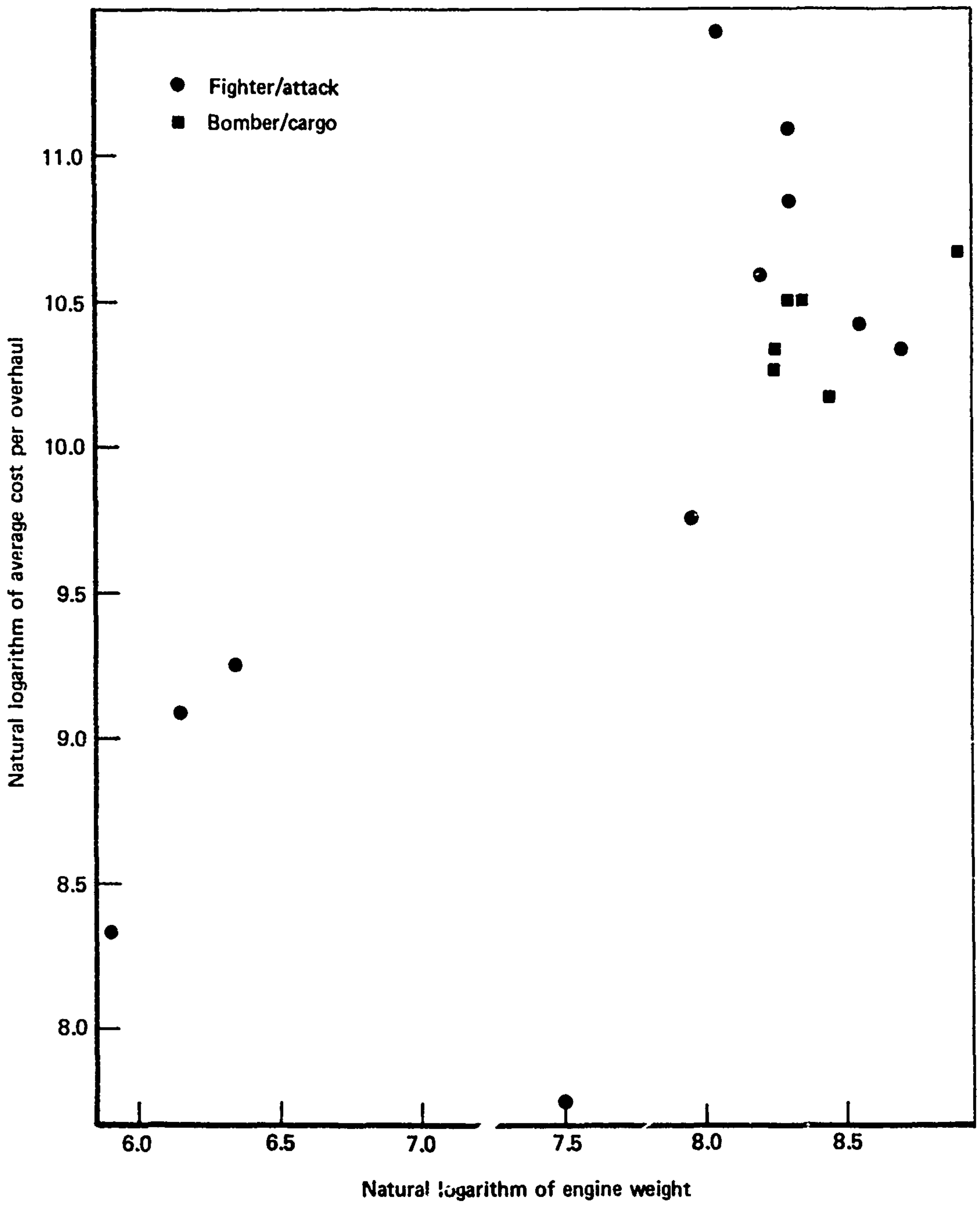

Fig. E.22—Variation of overhaul cost with engine weight

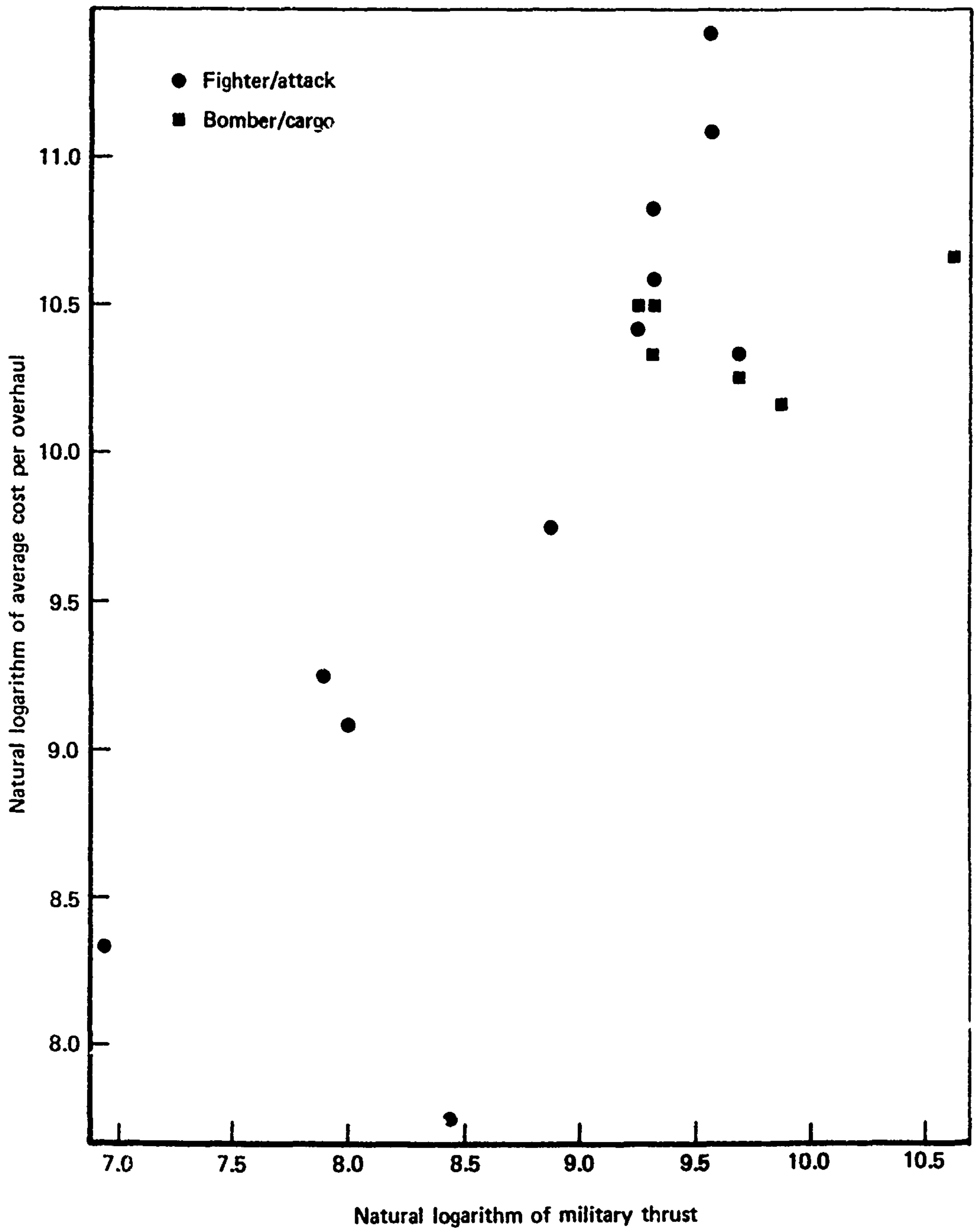

Fig. E.23—Variation of overhaul cost with military thrust

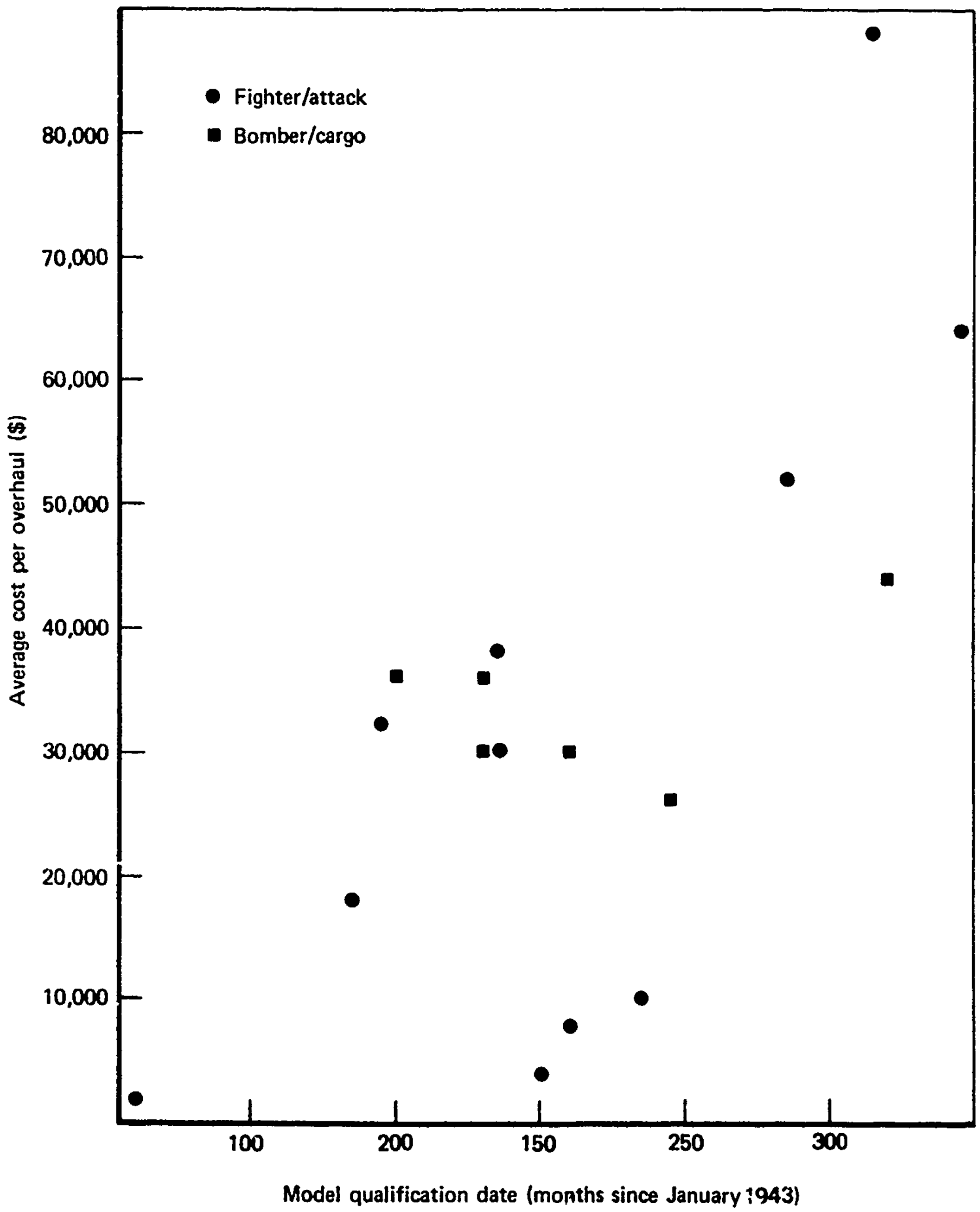

Fig. E.24—Variation of overhaul cost with model qualification date

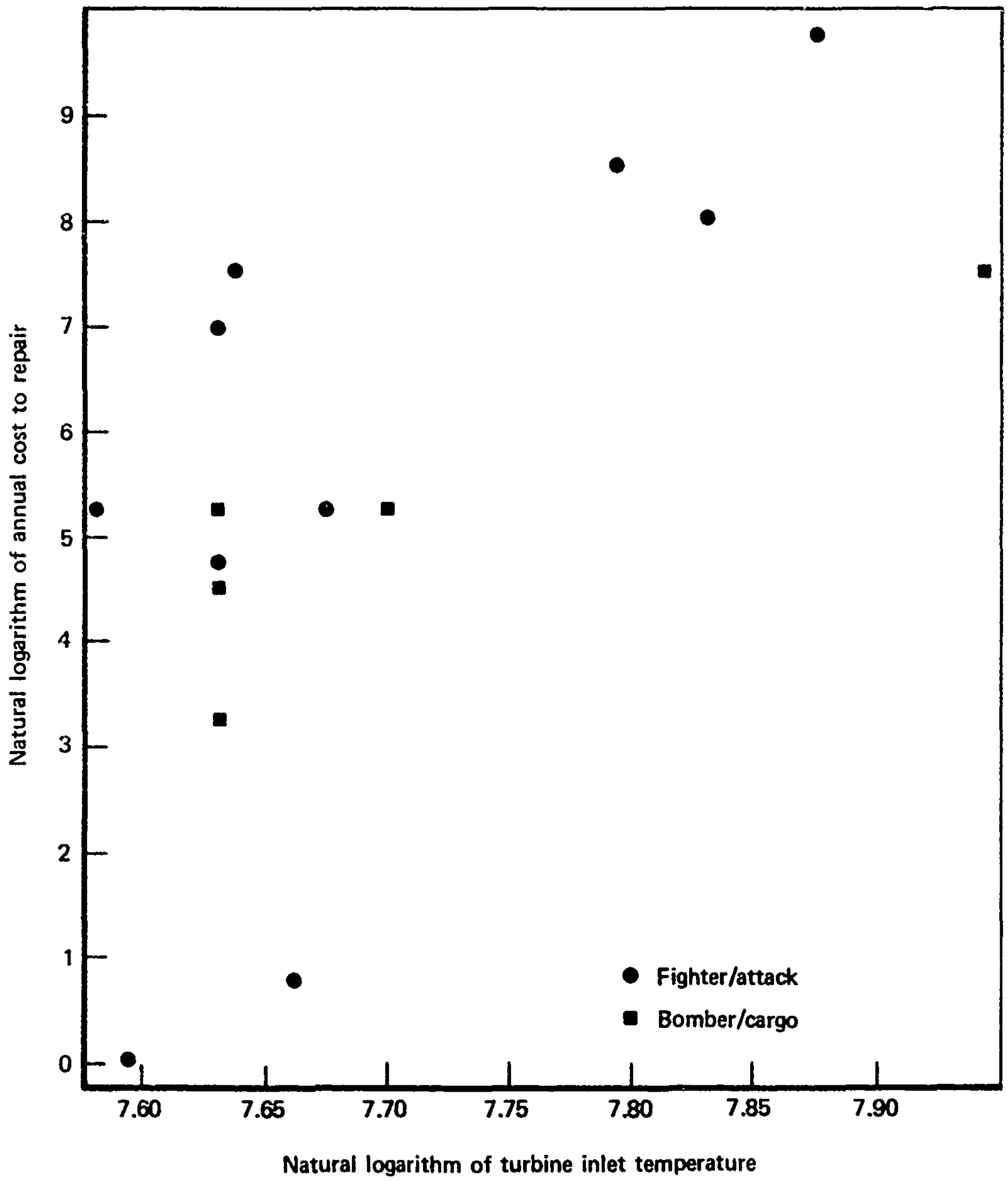

Fig. E.25—Variation of annual cost to repair with turbine inlet temperature

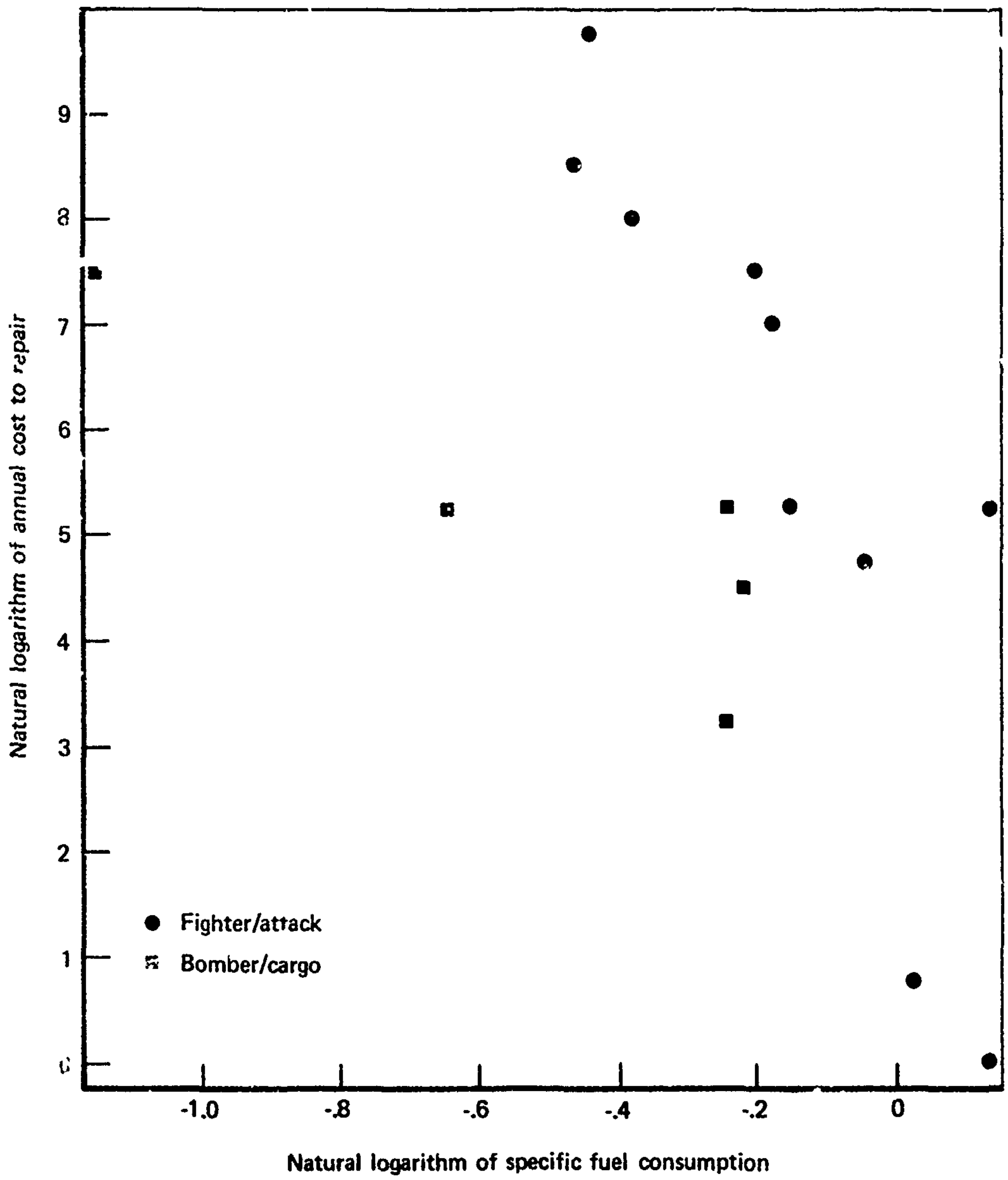

Fig. E.26—Variation of annual cost to repair with specific fuel consumption

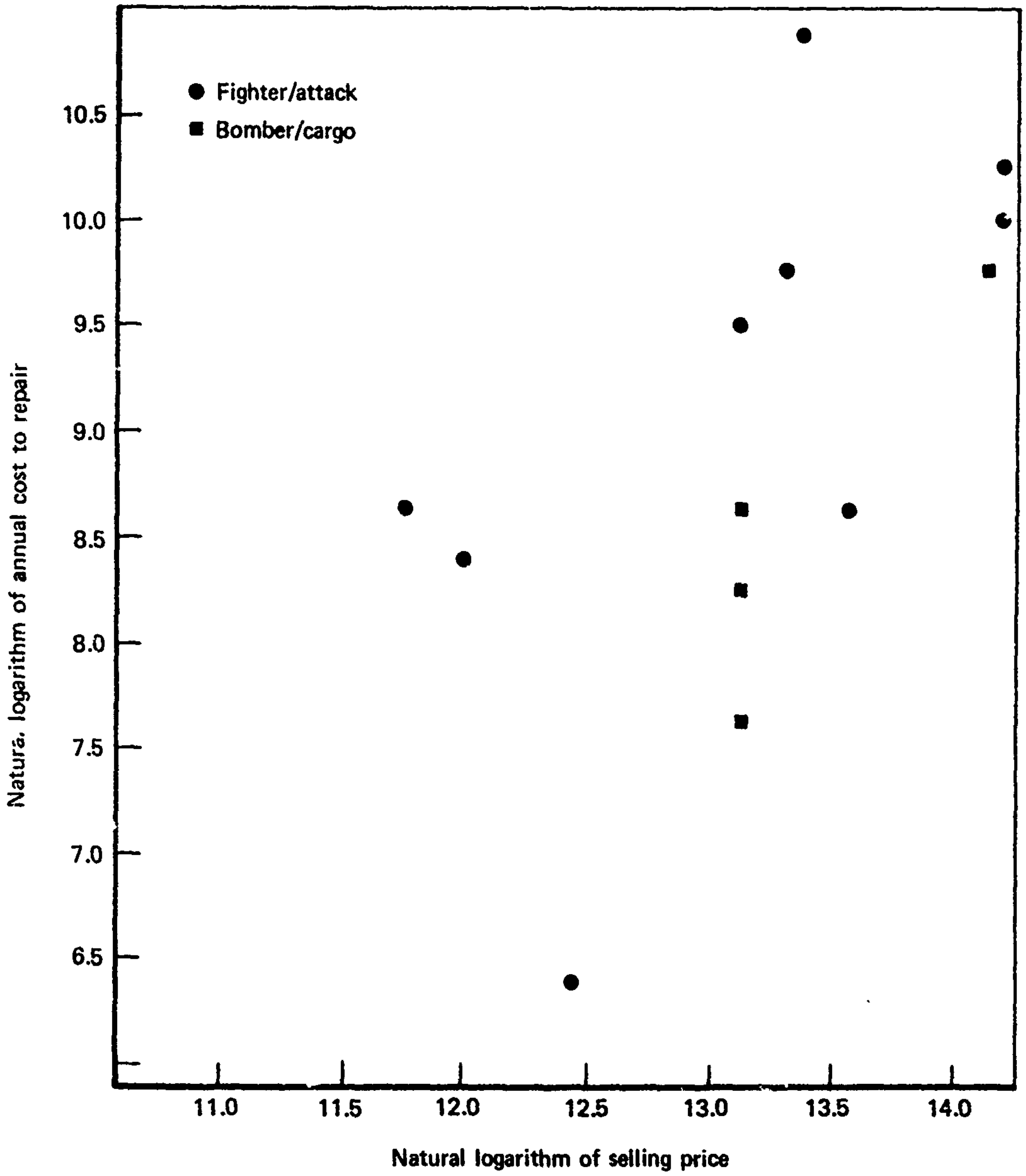

Fig. E.27—Variation of annual cost to repair with selling price

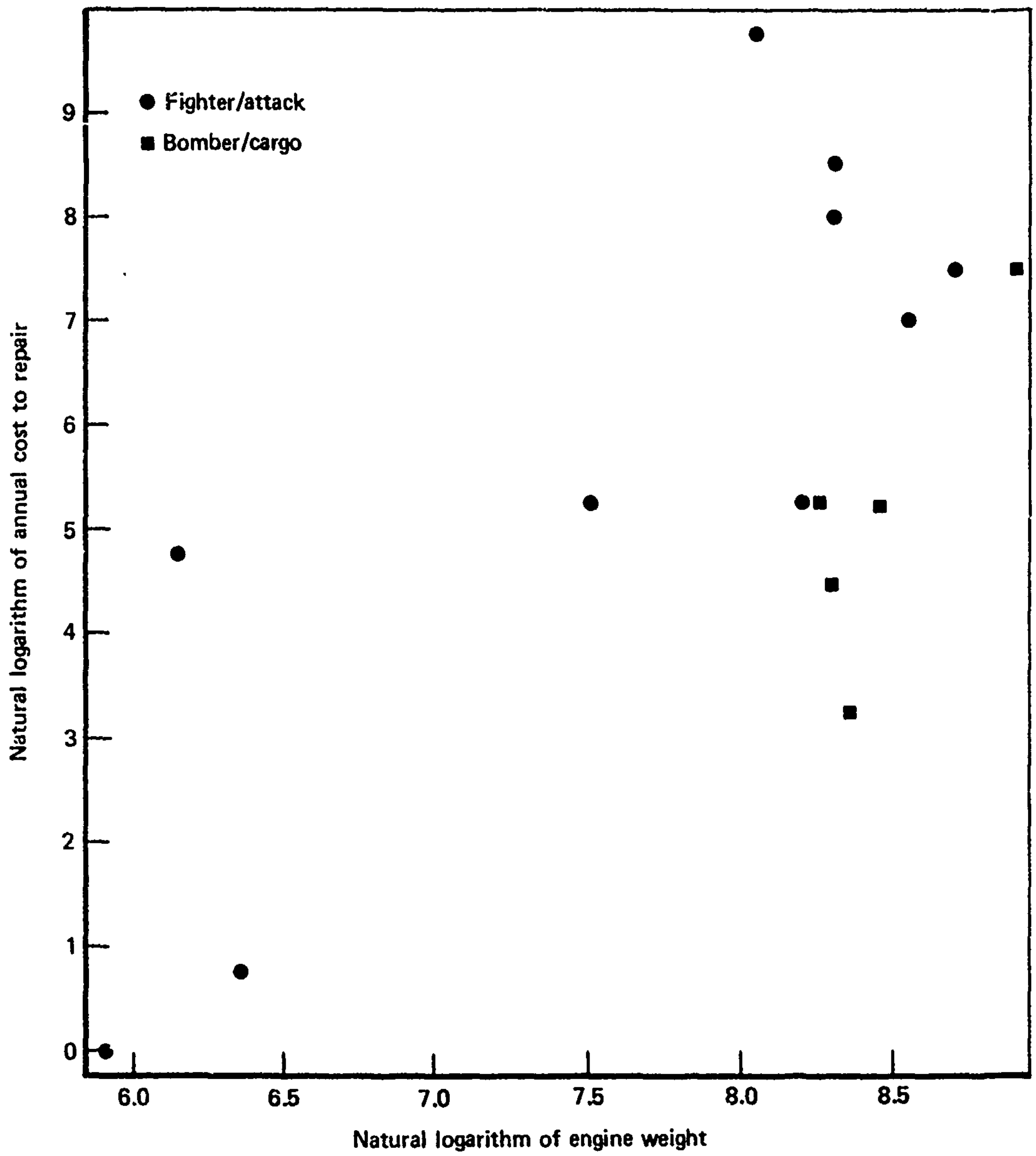

Fig. E.28—Variation of annual cost to repair with engine weight

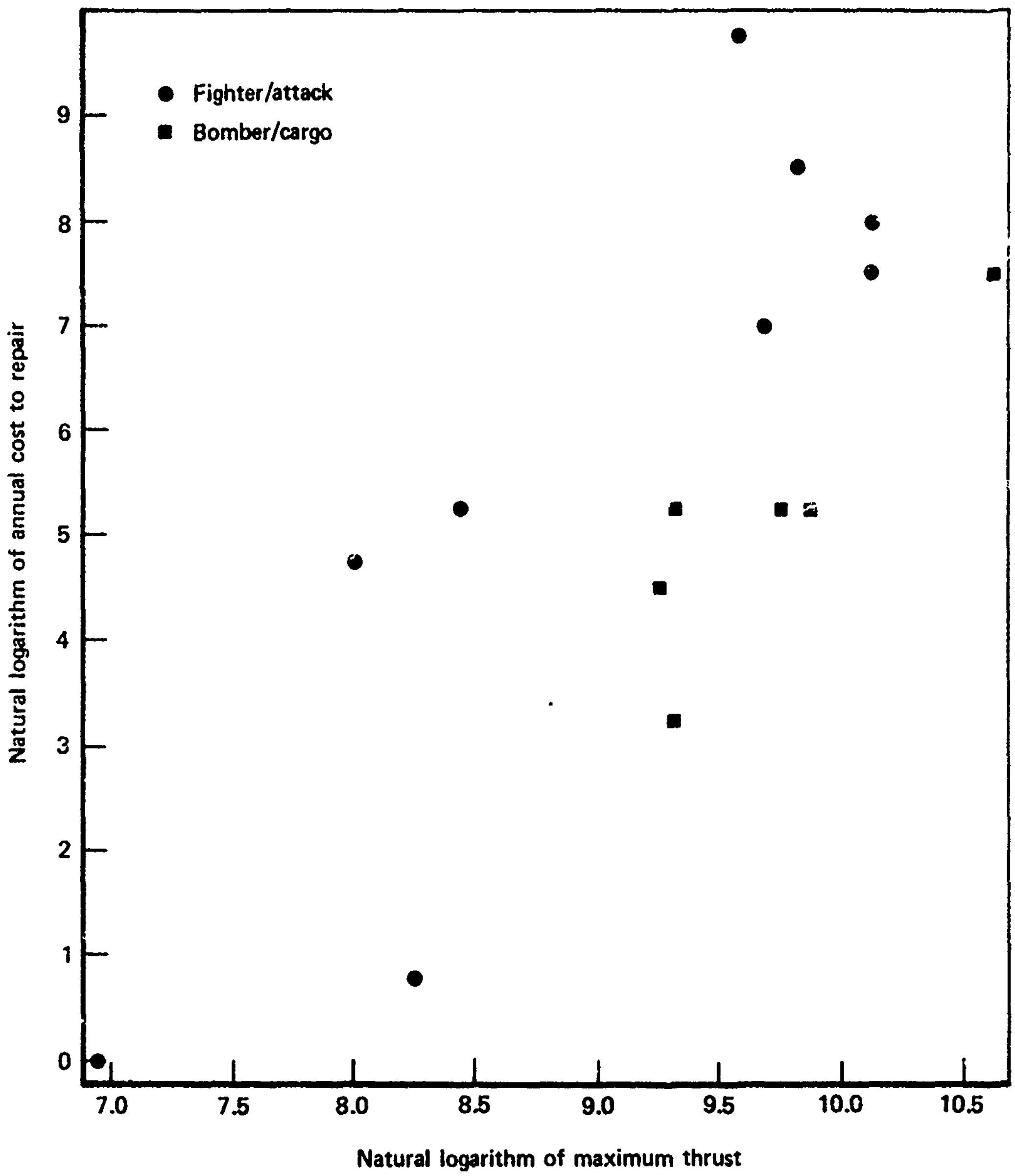

Fig. E.29—Variation in annual cost to repair with maximum thrust

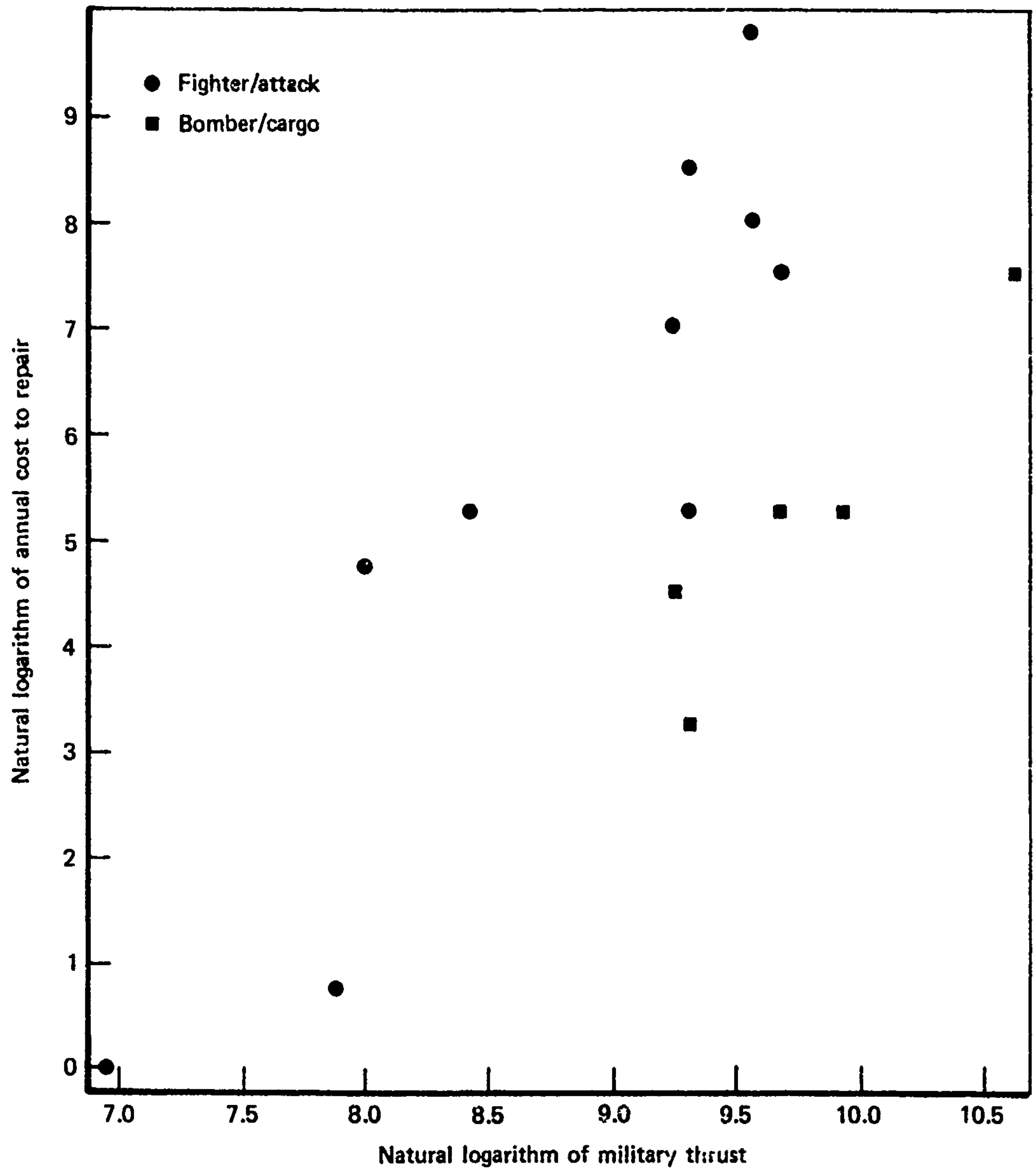

Fig. E.30—Variation in annual cost to repair with military thrust

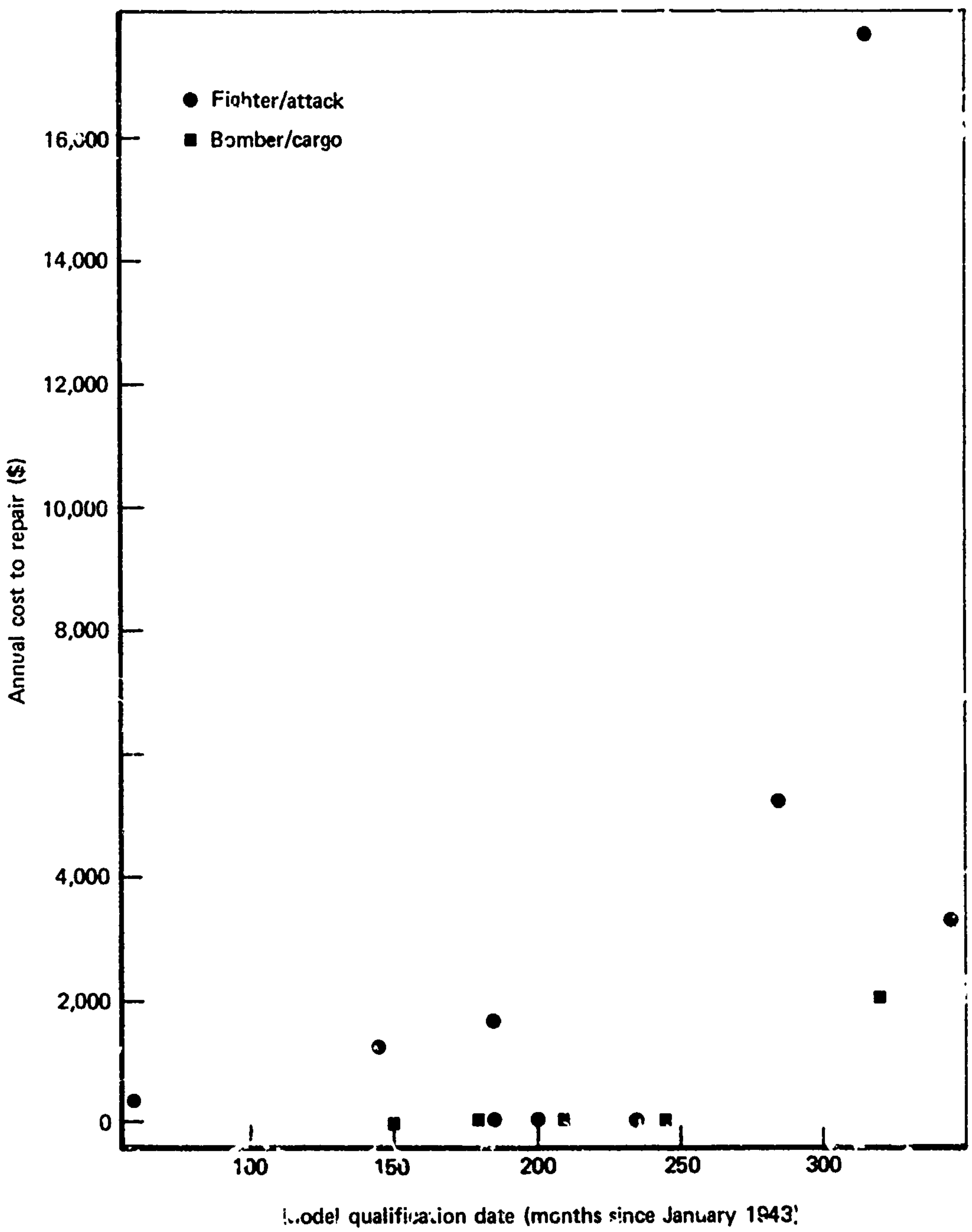

Fig. E.31—Variation of annual cost to repair with model qualification date

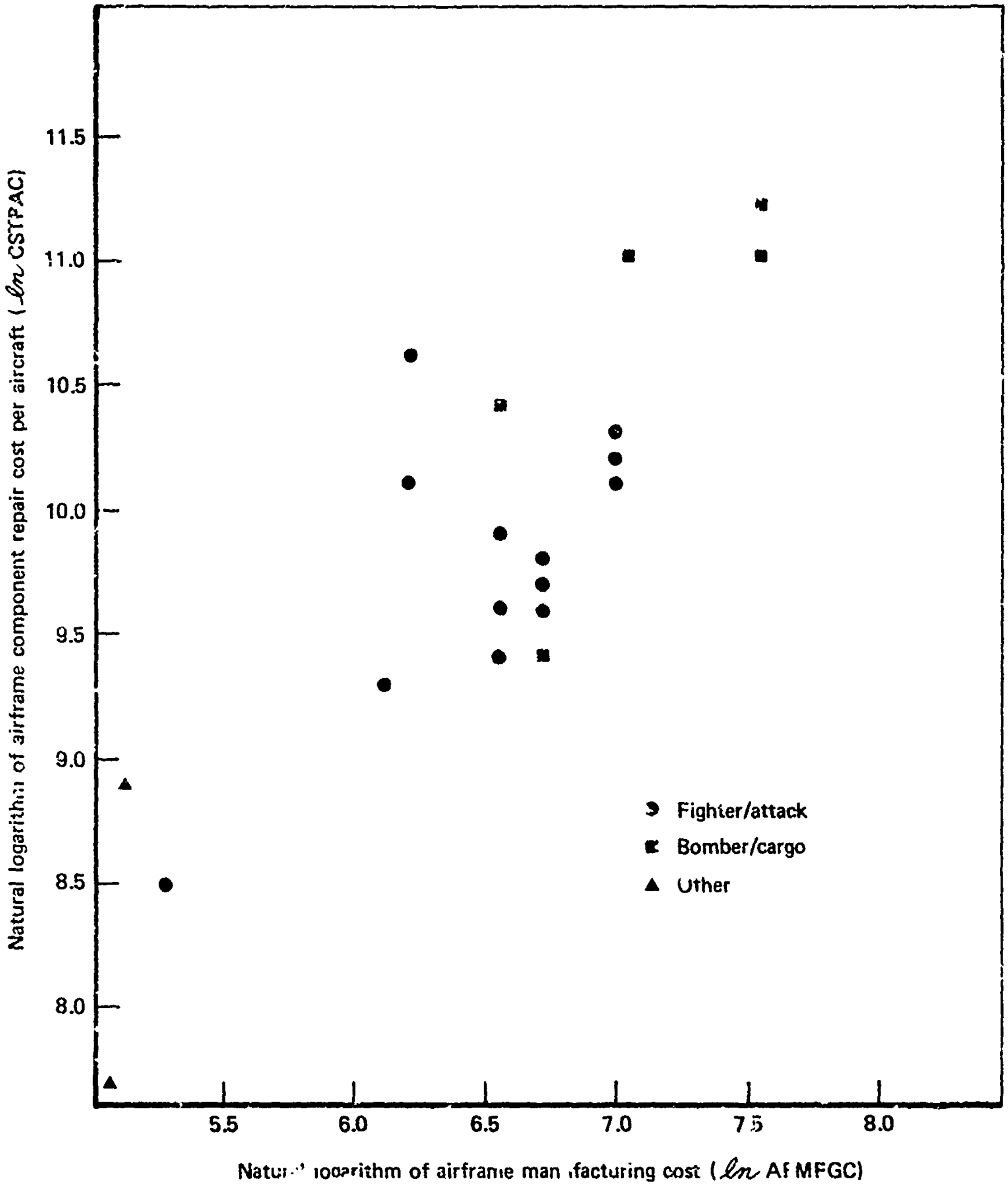

Fig. E.32—Variation of airframe component repair cost with airframe manufacturing cost

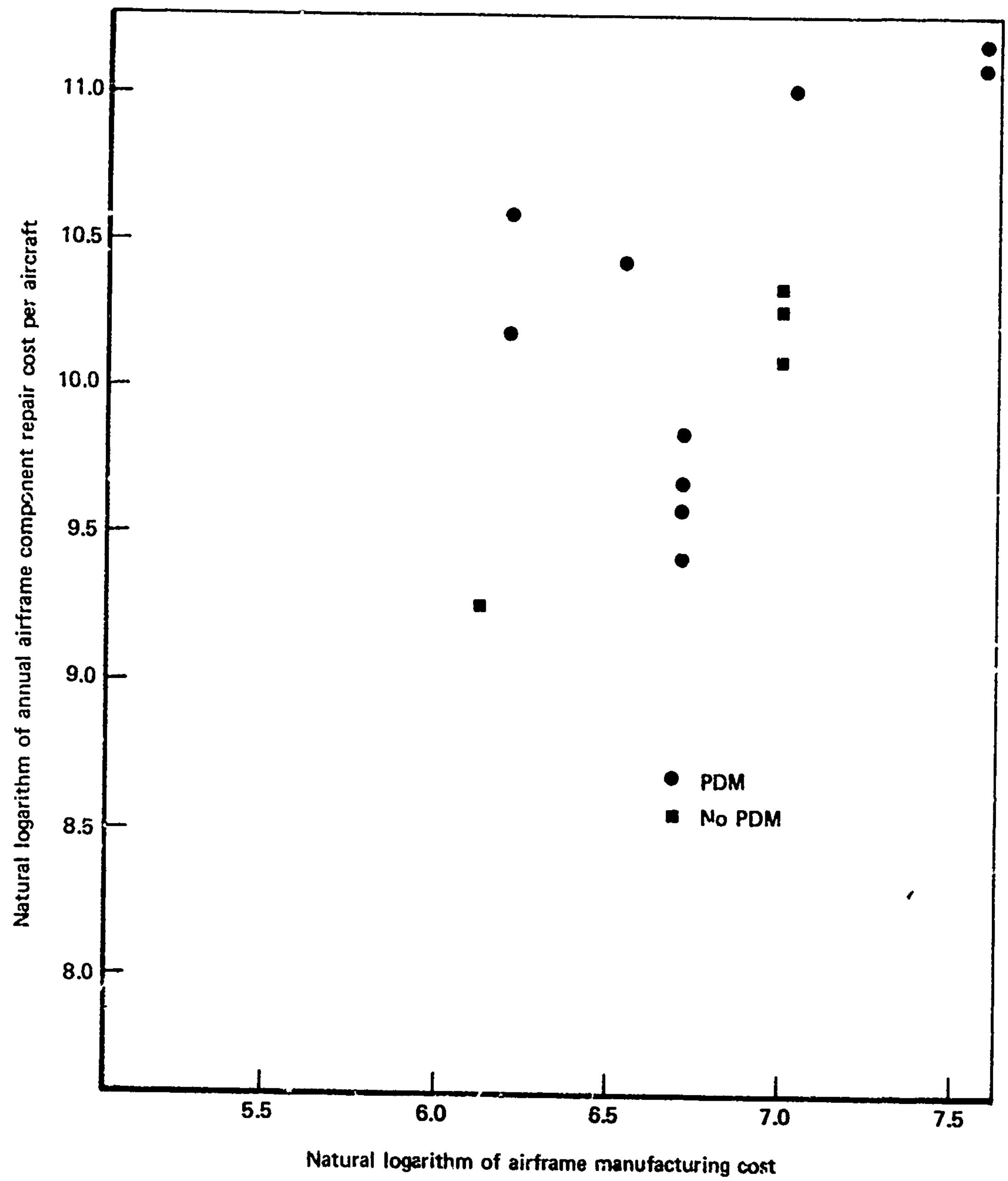

Fig. E.33—Variation of airframe component repair cost with airframe manufacturing cost

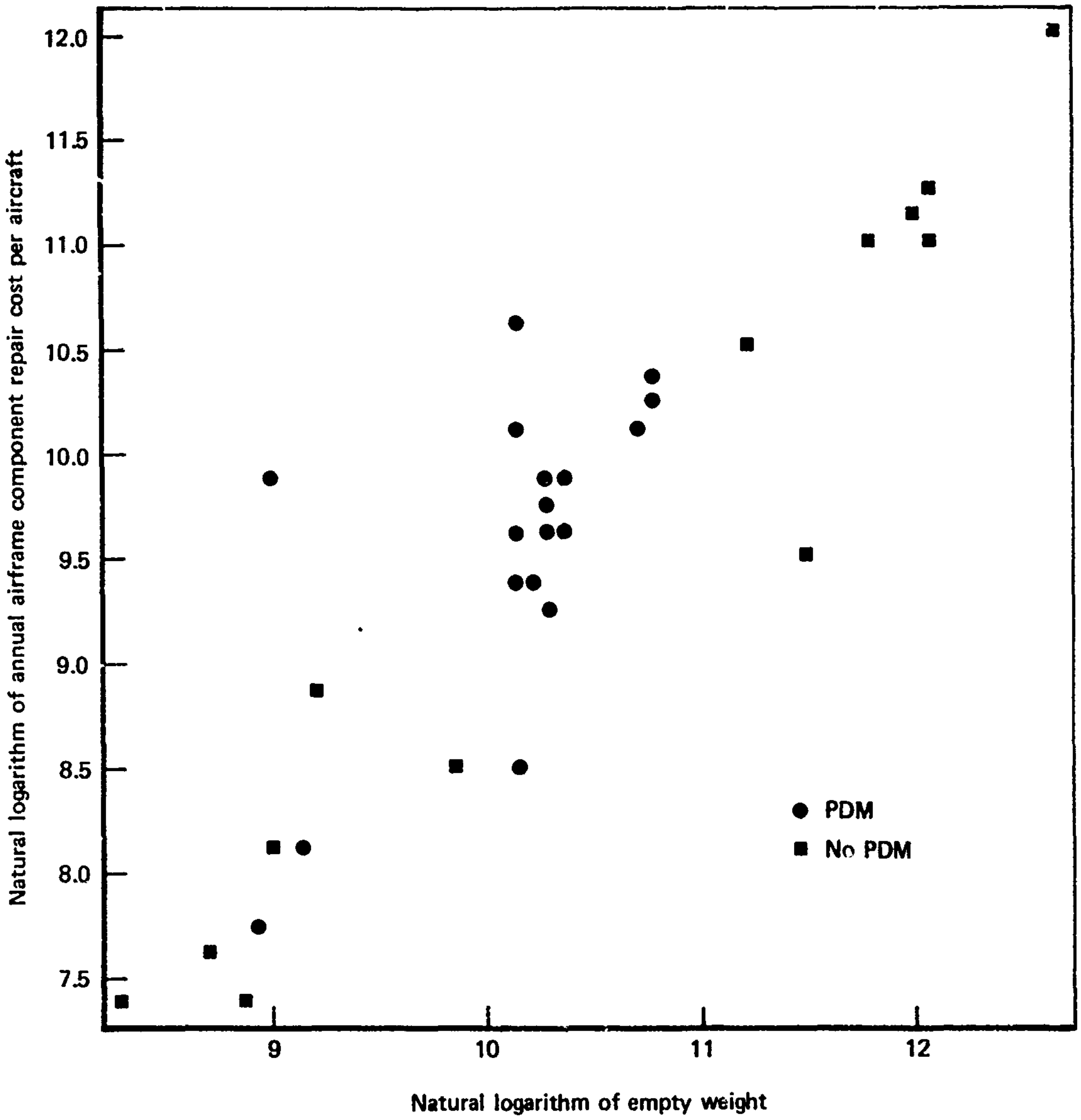

Fig. E.34—Variation of airframe component repair cost with empty weight and PDM policy

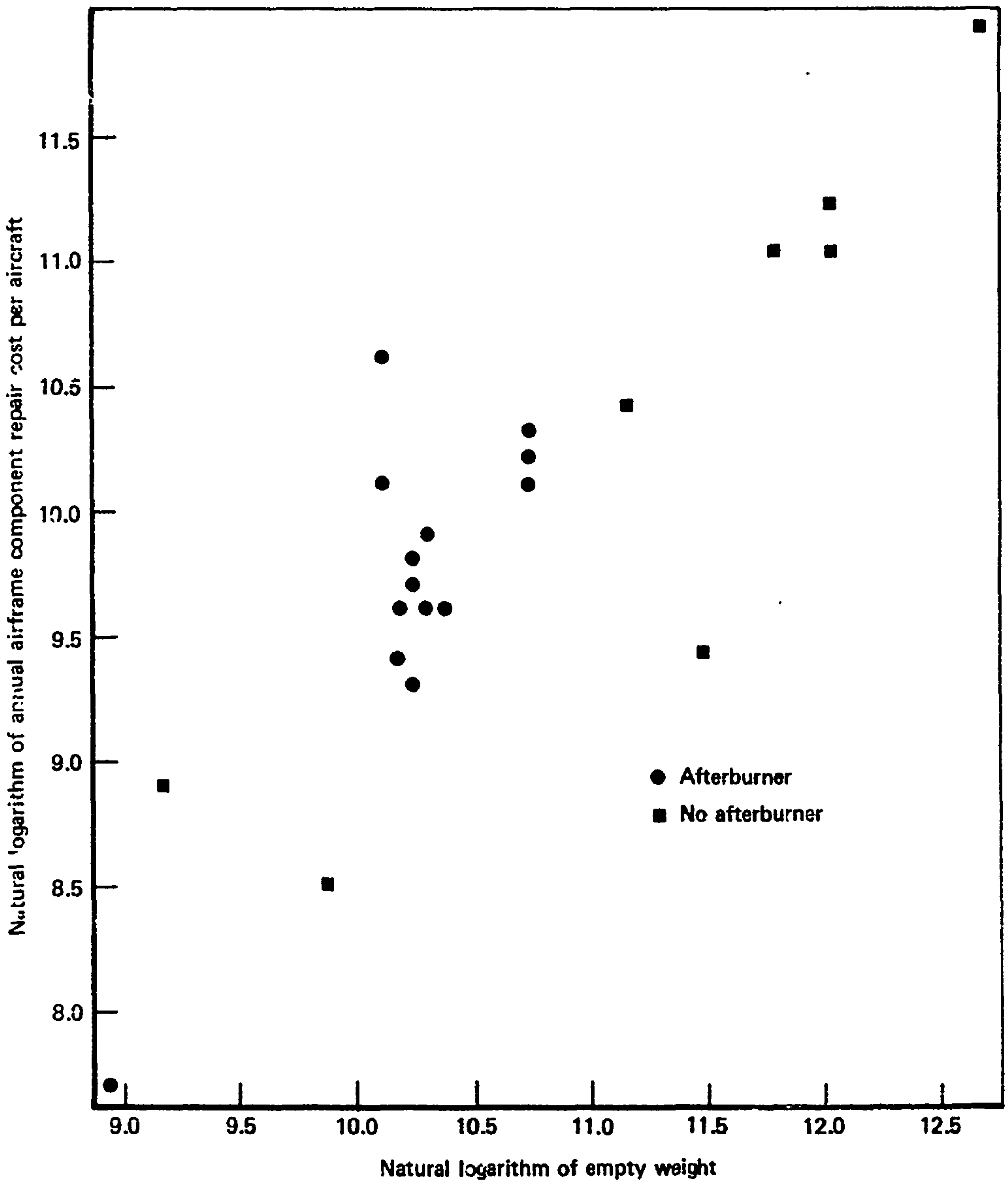

Fig. E.35—Variation of airframe component repair cost with empty weight and afterburner

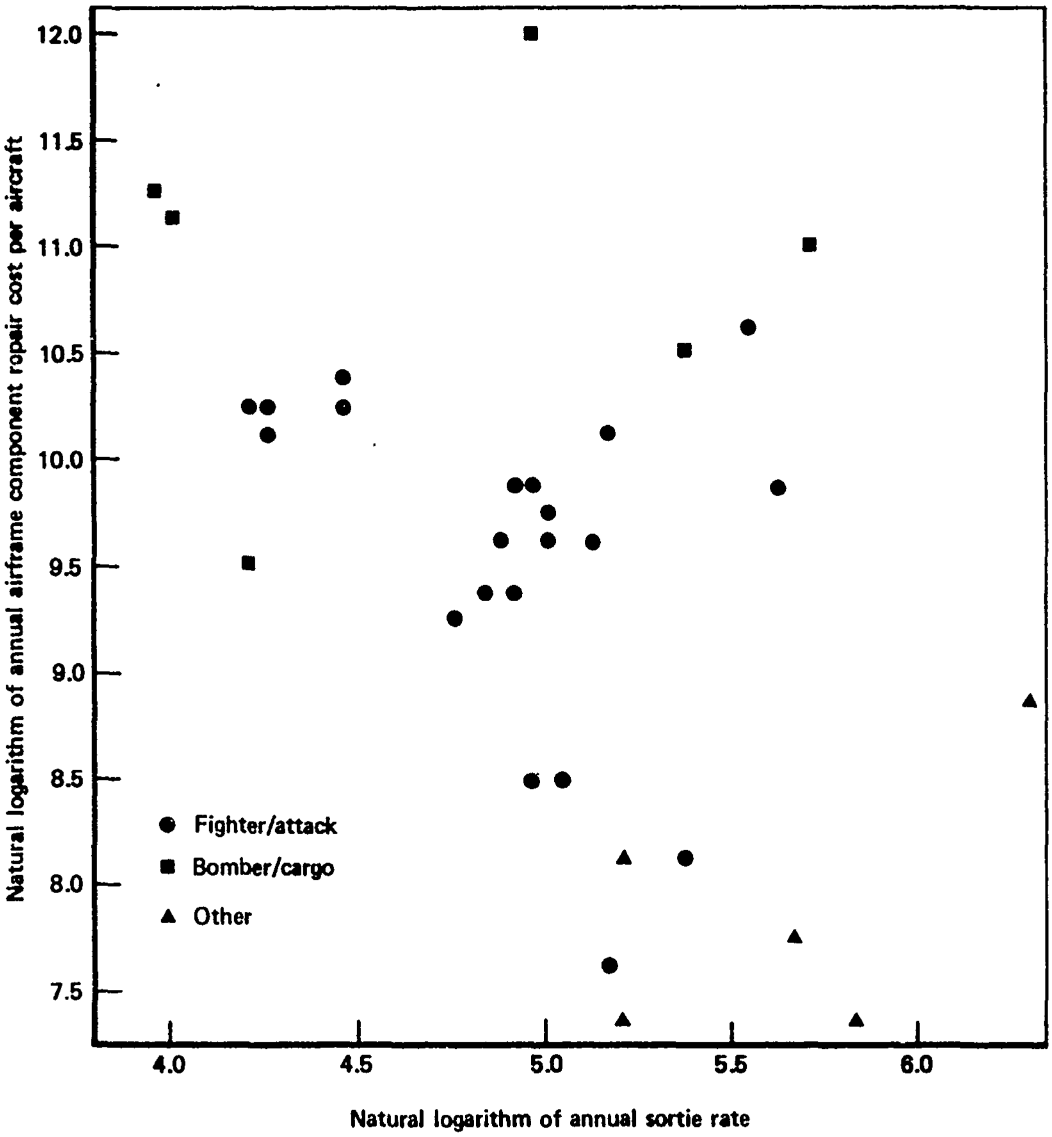

Fig. E.36—Variation of airframe component repair cost with sortie rate

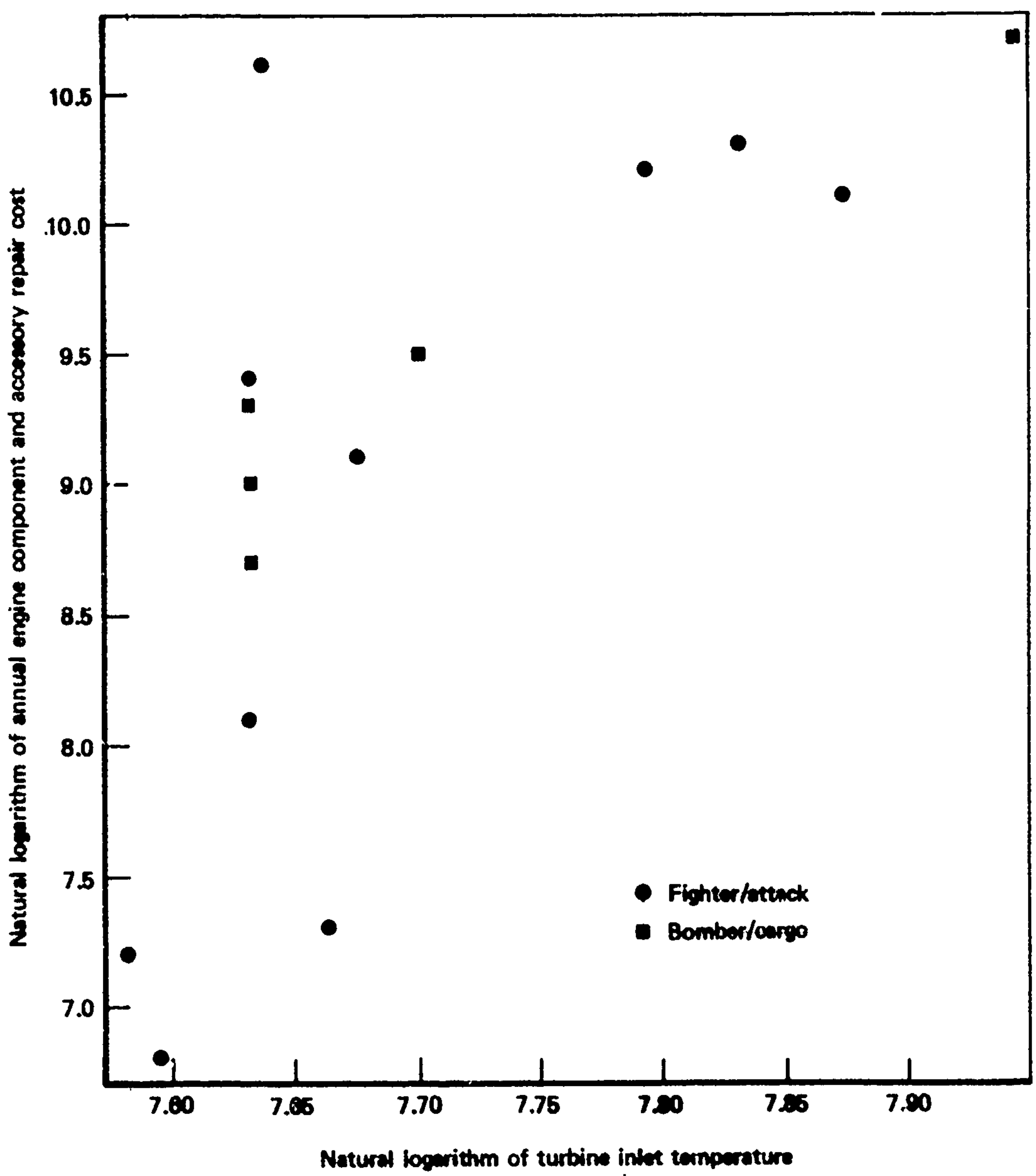

Fig. E.37—Variation of annual engine component and accessory repair cost with turbine inlet temperature

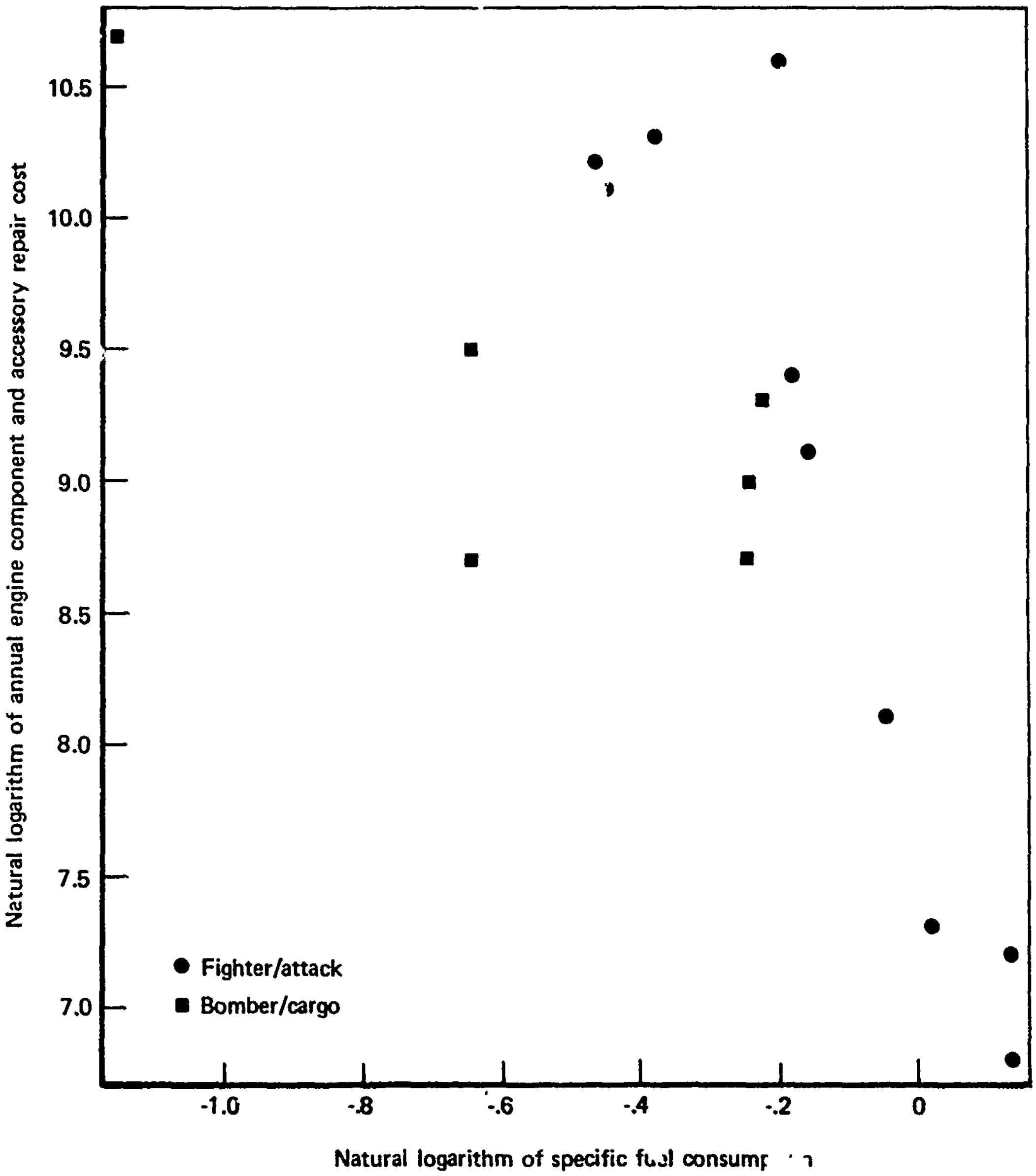

Fig. E.38—Variation of annual engine component and accessory repair cost with specific fuel consumption

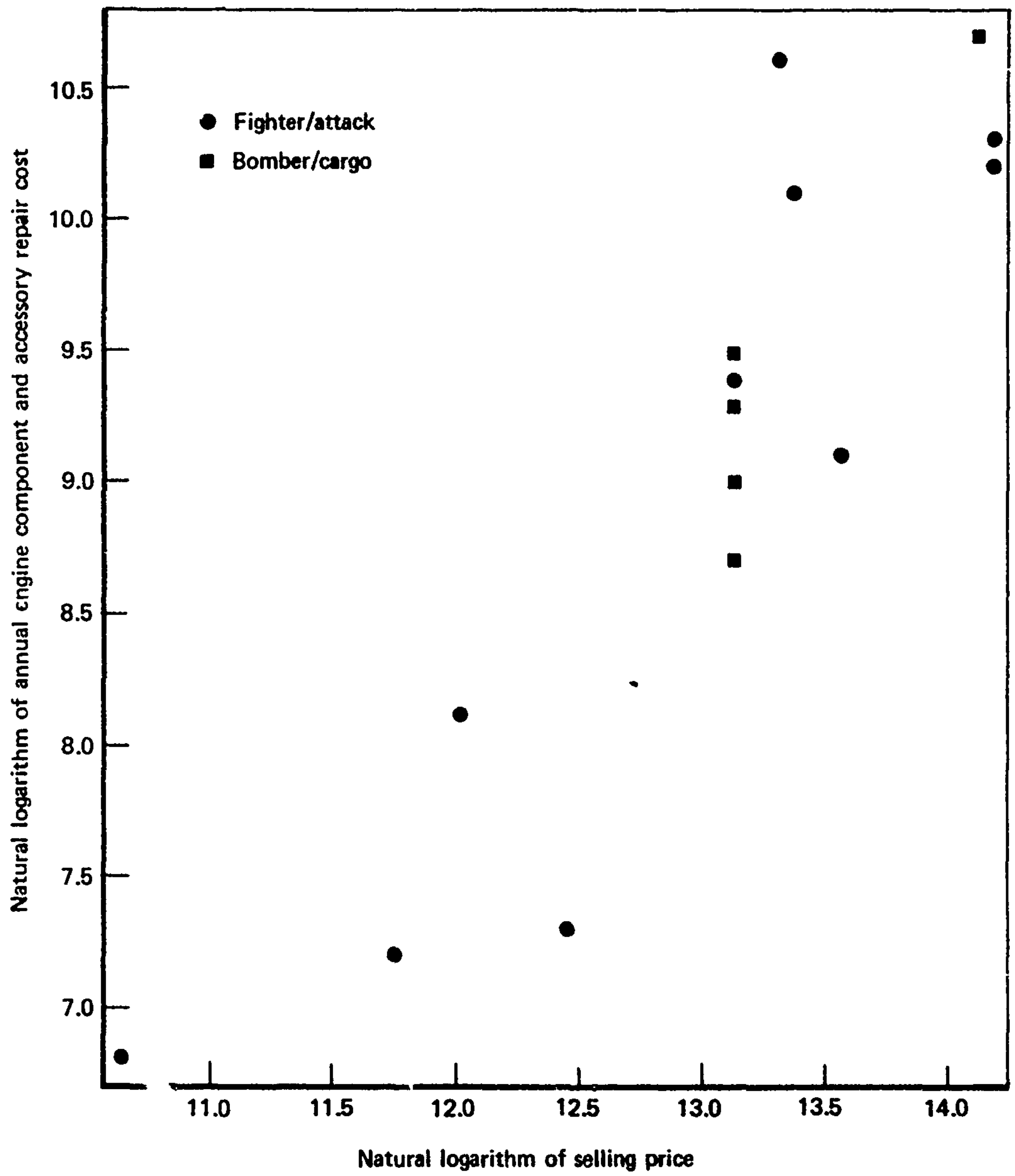

Fig. E.39—Variation in annual engine component and accessory repair cost with selling price

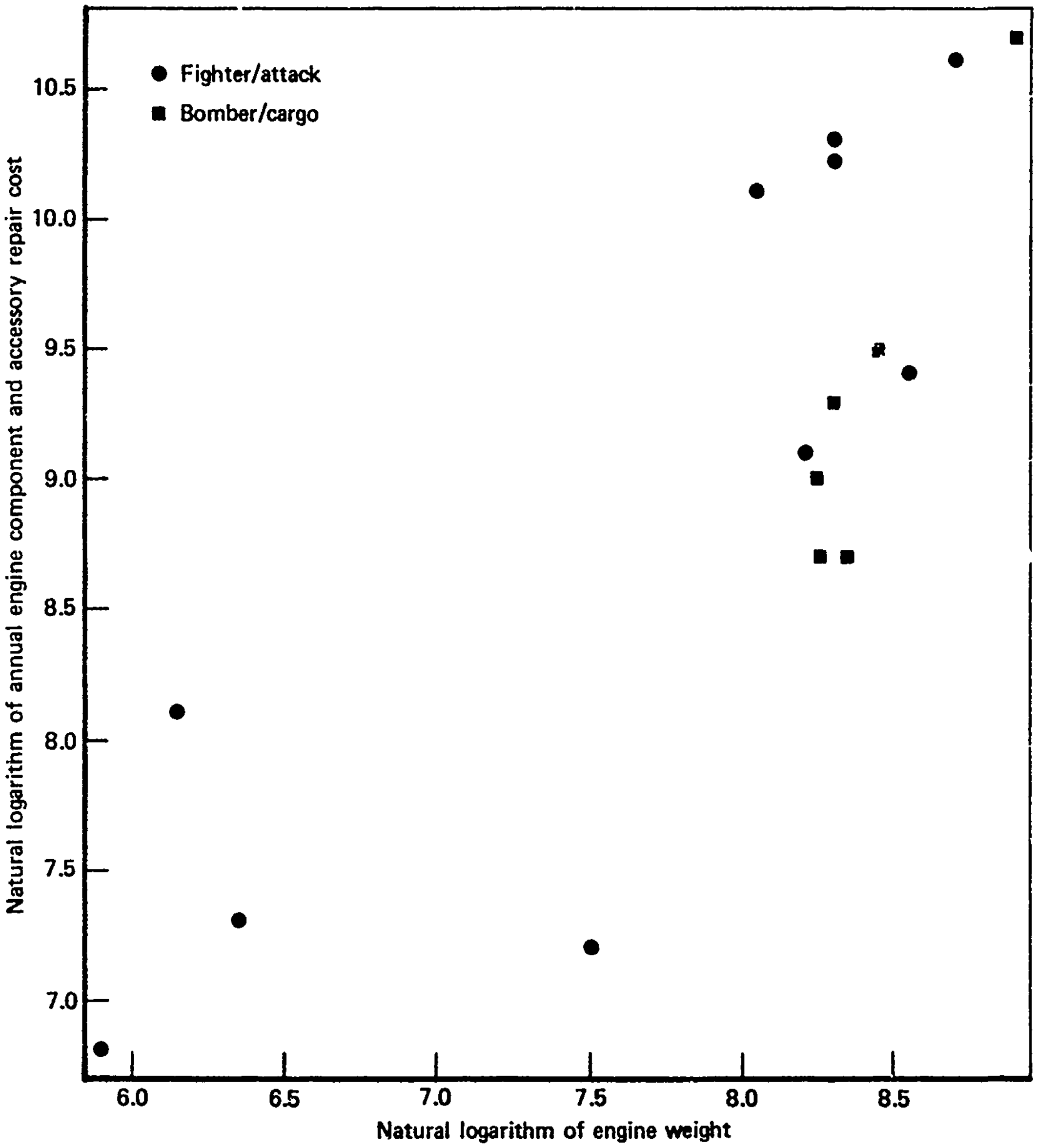

Fig. E.40—Variation in annual engine component and accessory repair cost with engine weight

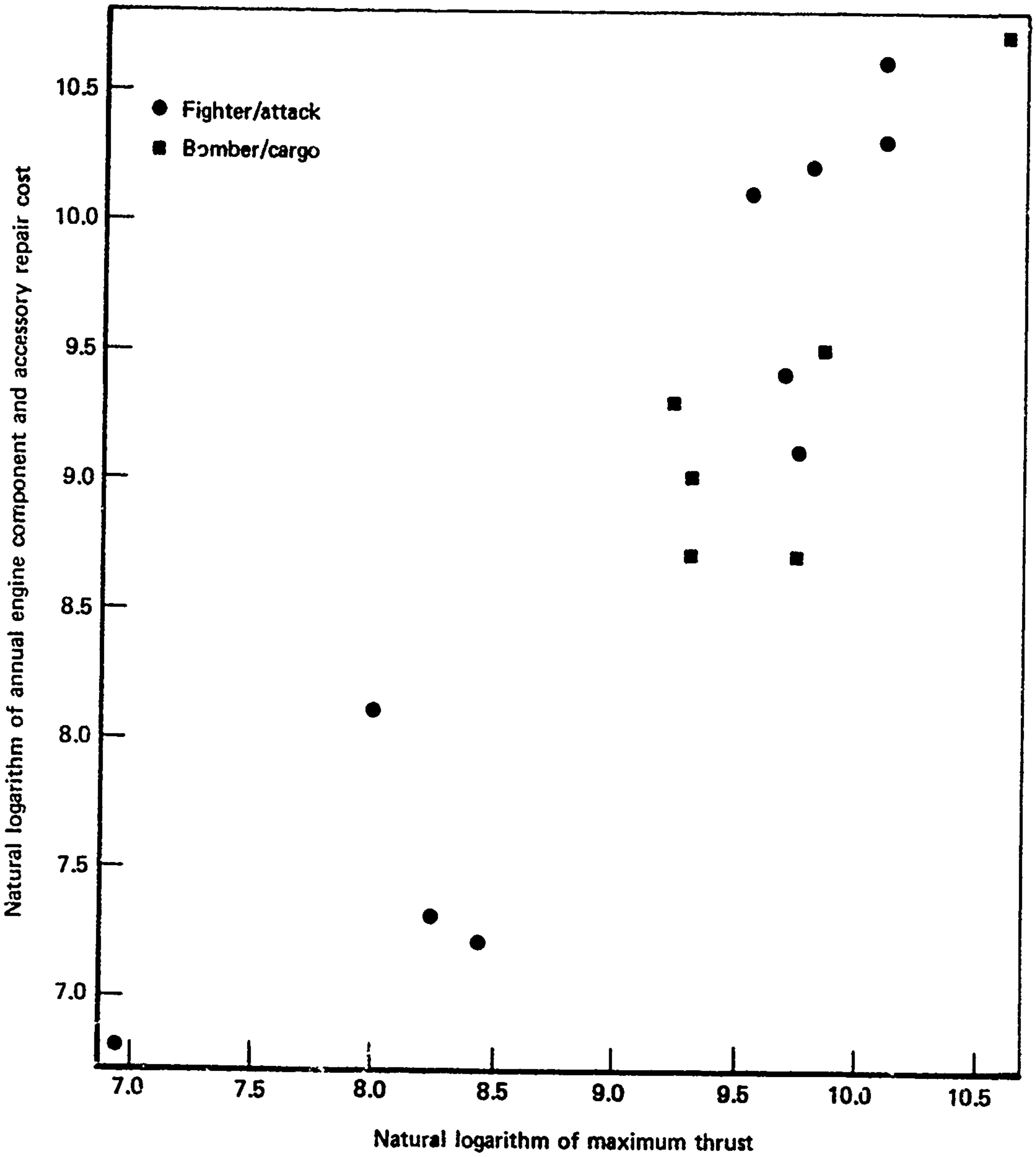

Fig. E.41—Variation in annual engine component and accessory repair cost with maximum thrust

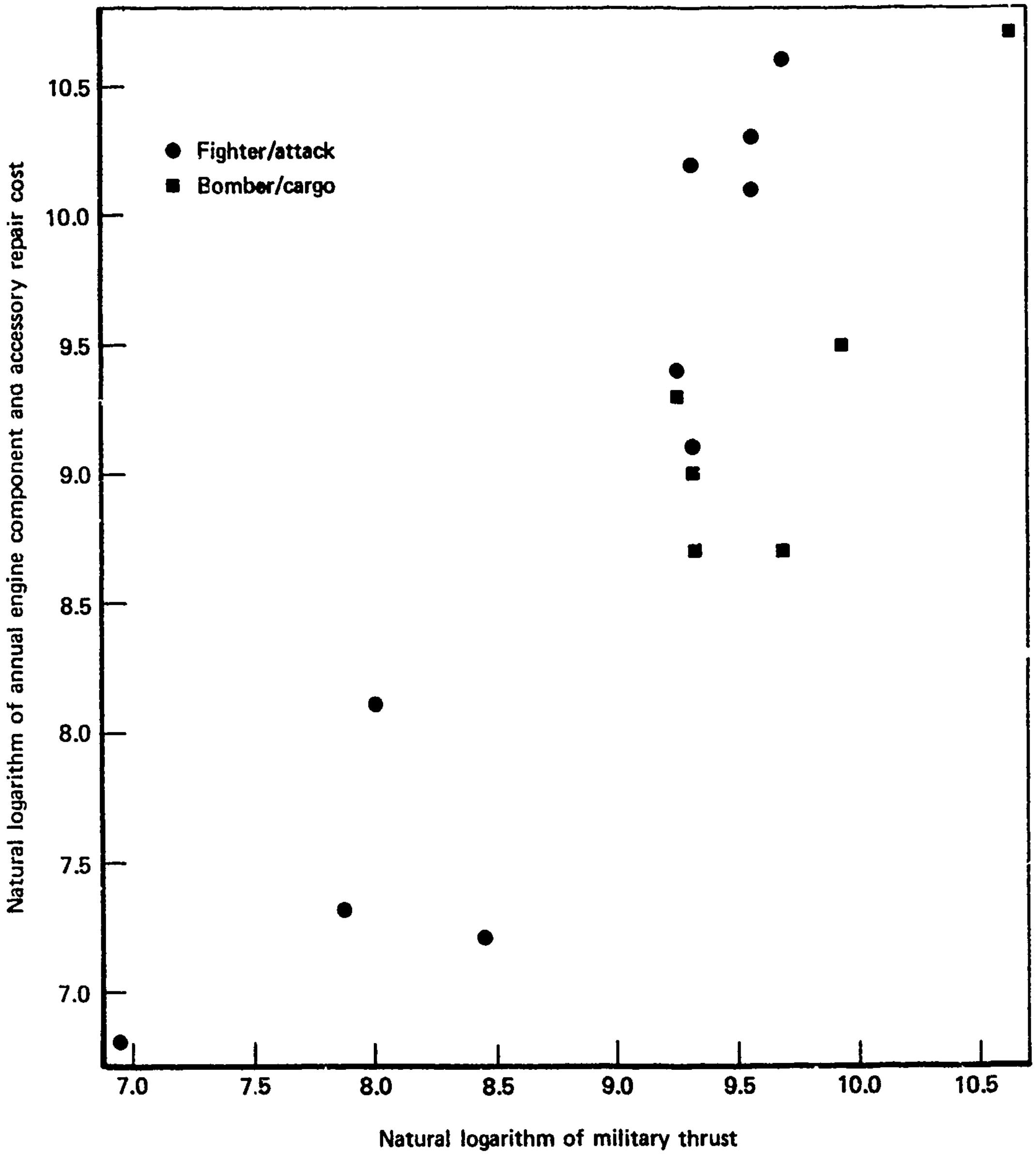

Fig. E.42—Variation of annual engine component and accessory repair cost with military thrust

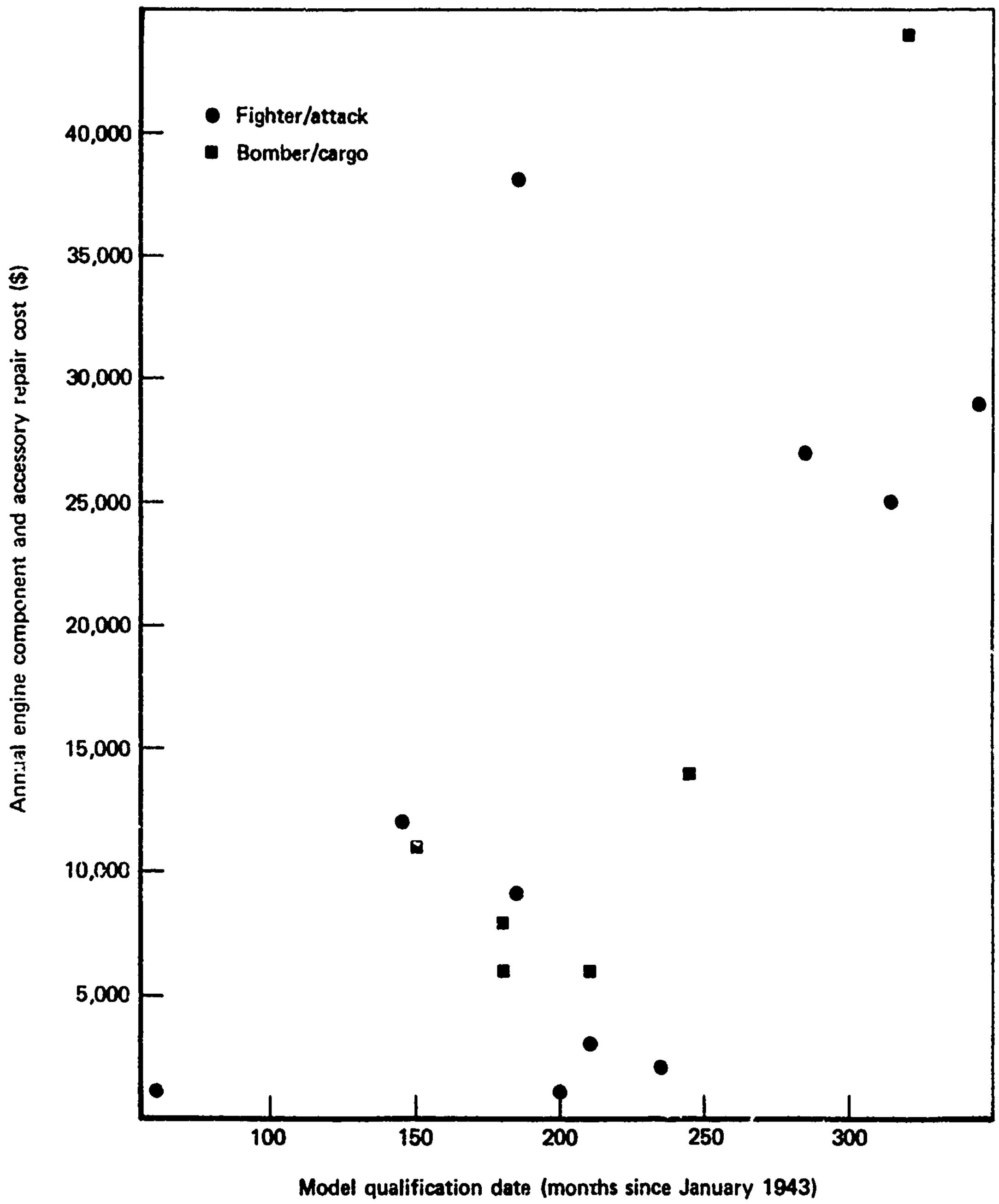

Fig. E.43—Variation in annual engine component and accessory repair cost with model qualification date

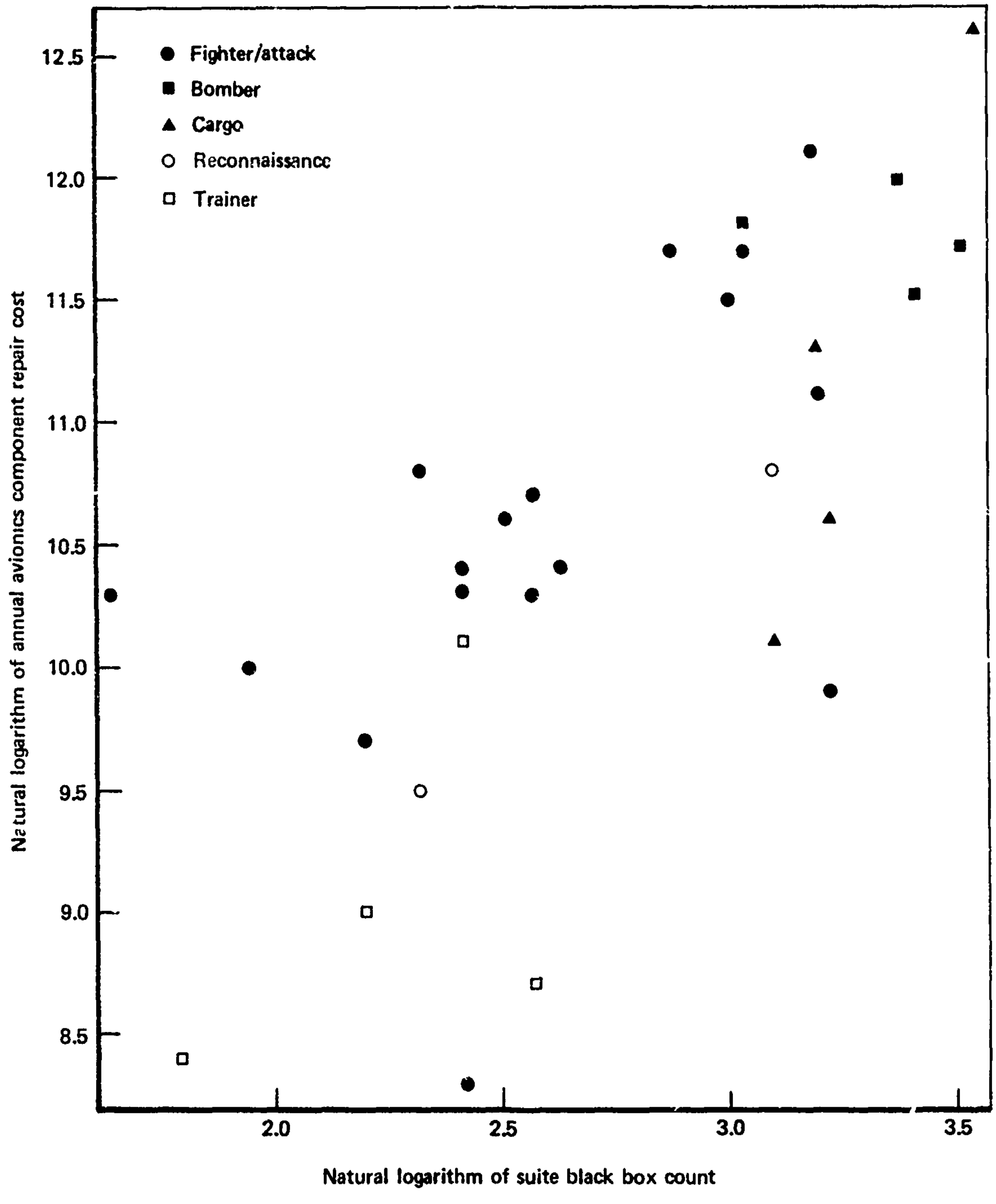

Fig. E.44—Variation of annual avionics component repair cost with suite black box count

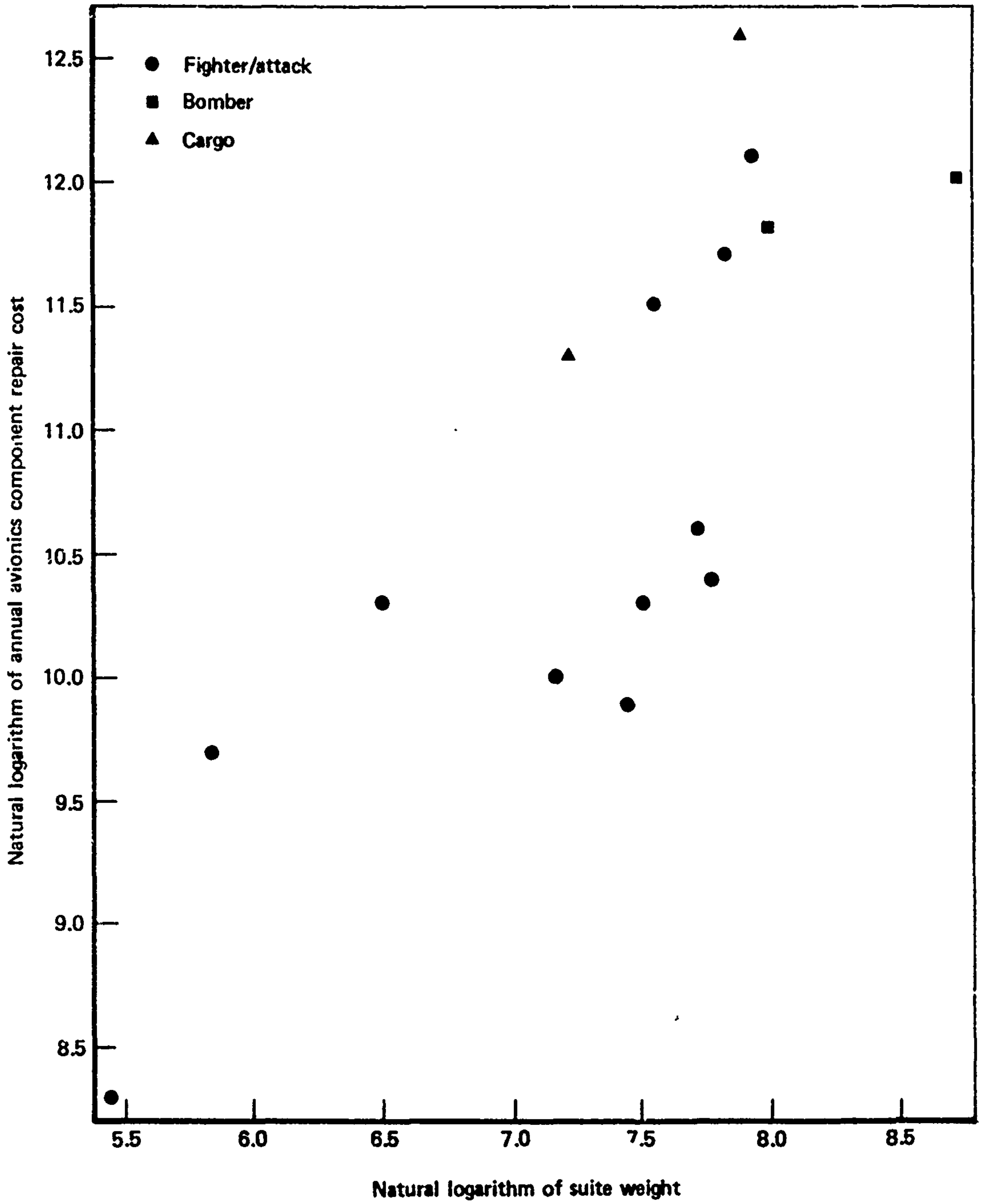

Fig. E.45—Variation of annual avionics component repair cost with suite weight

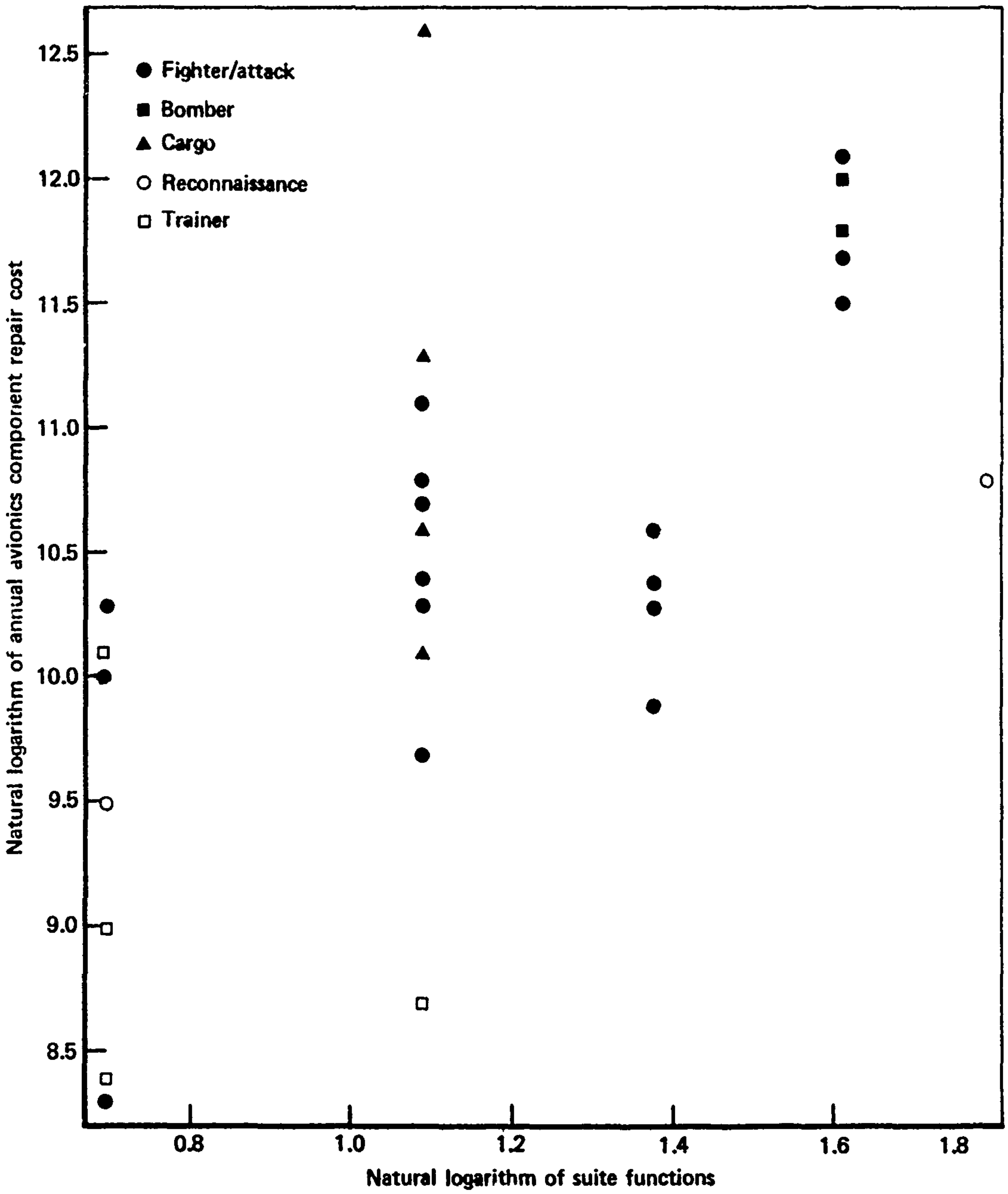

Fig. E.46—Variation of annual avionics component repair cost with suite functions

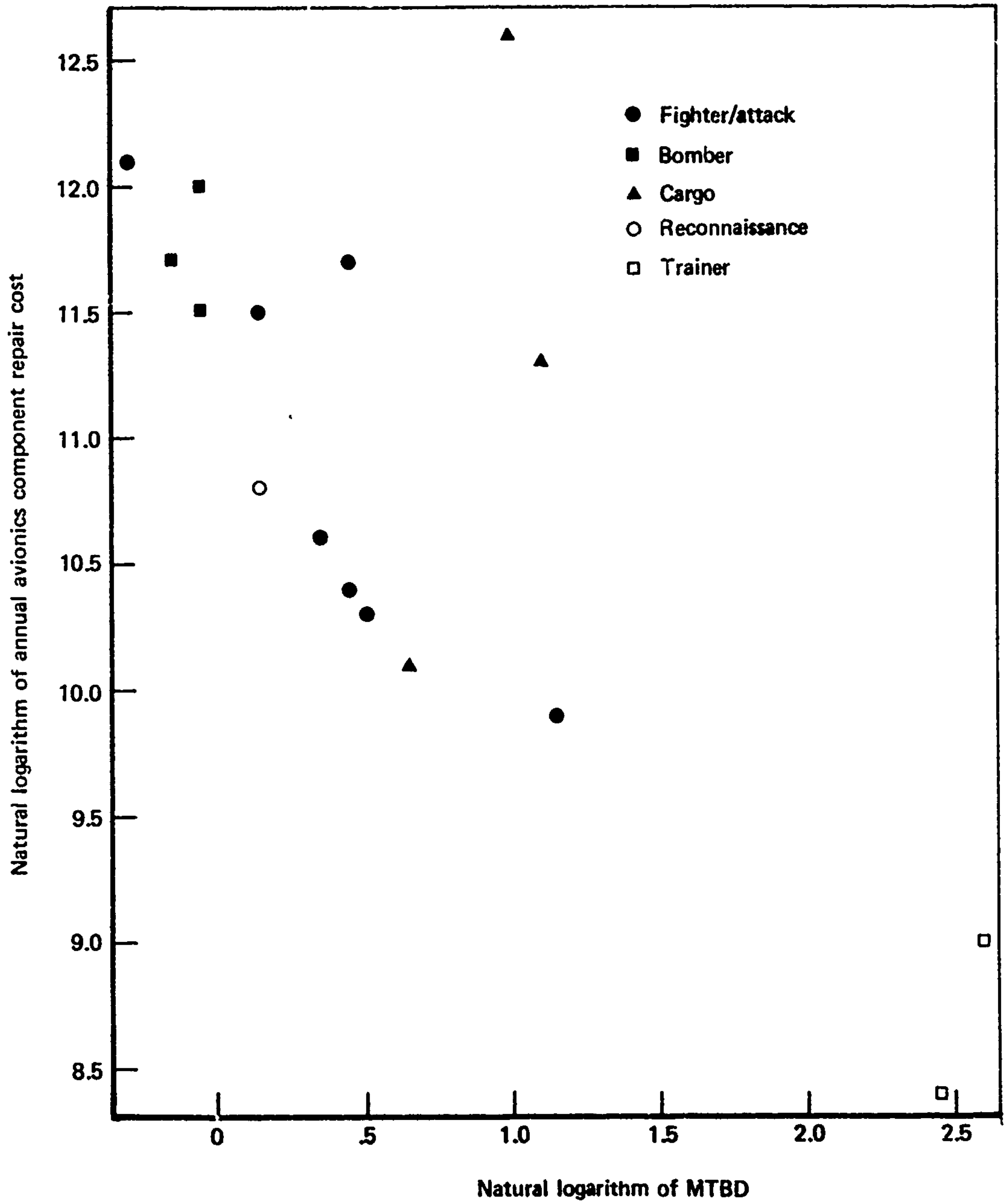

Fig. E.47—Variation of annual avionics component repair cost with MTBD (mean time between demands)

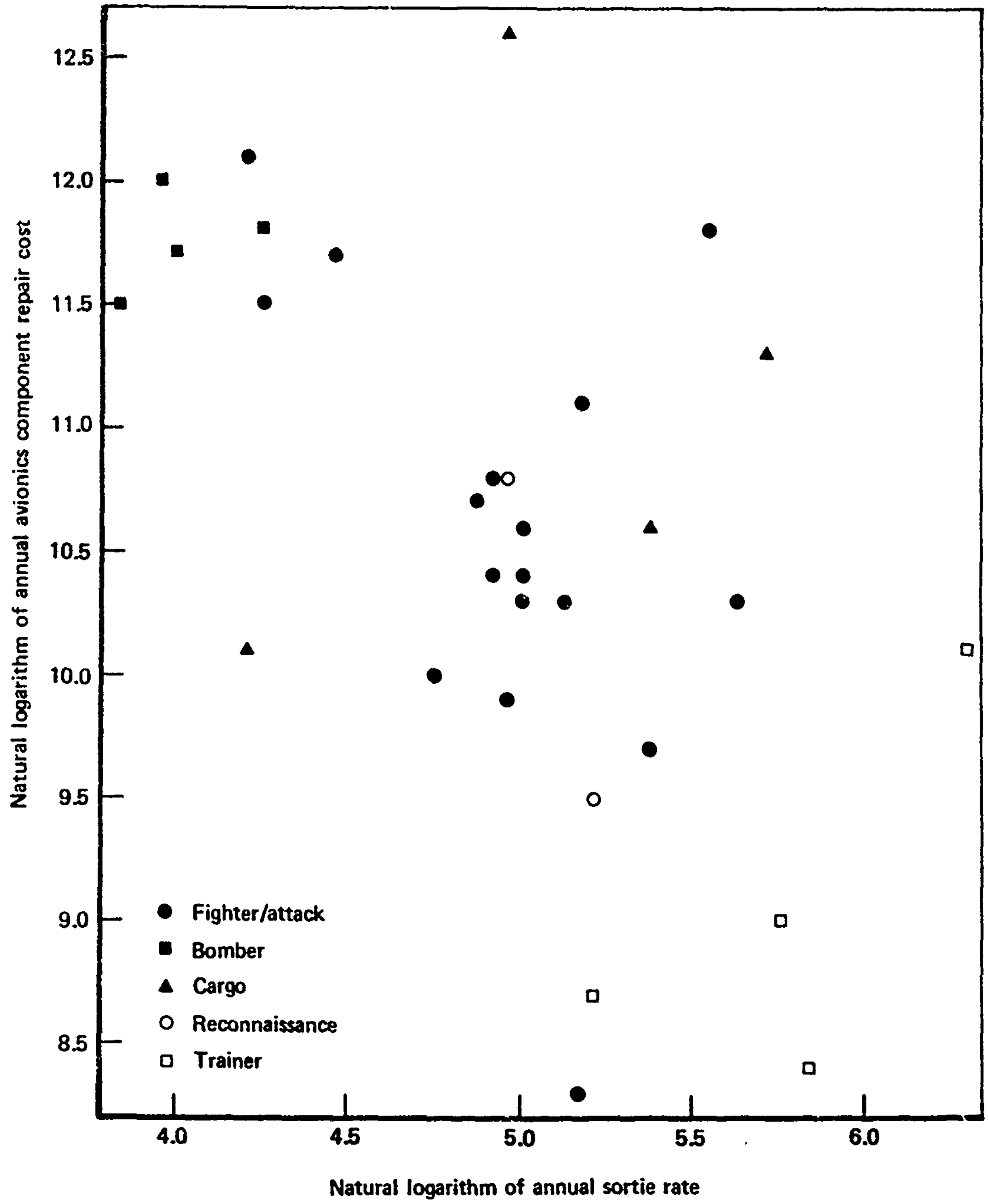

Fig. E.48—Variation of annual avionics component repair cost with annual sortie rate

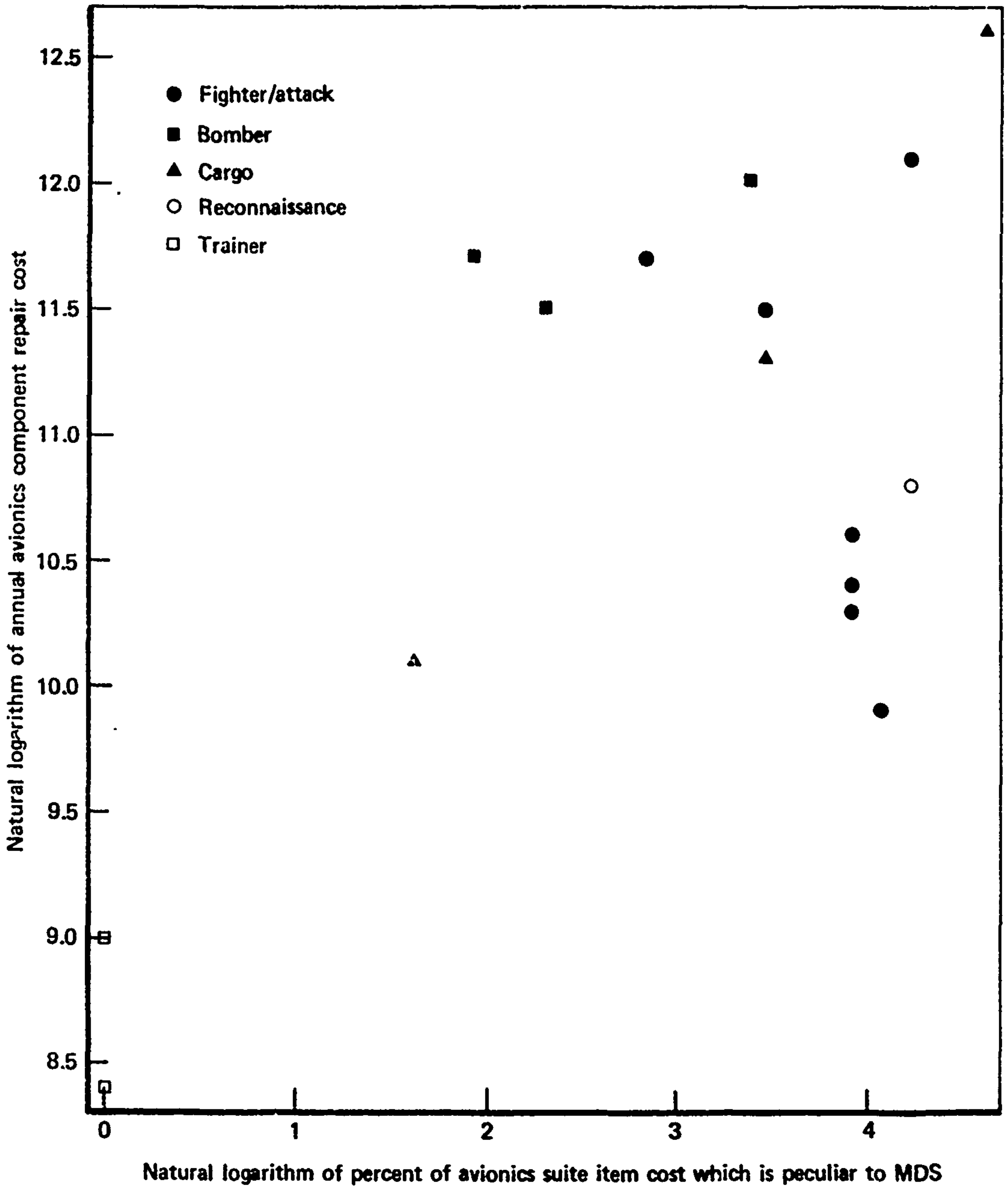

Fig. E.49—Variation of annual avionics component repair cost with percent of avionics suite item cost which is peculiar to MDS

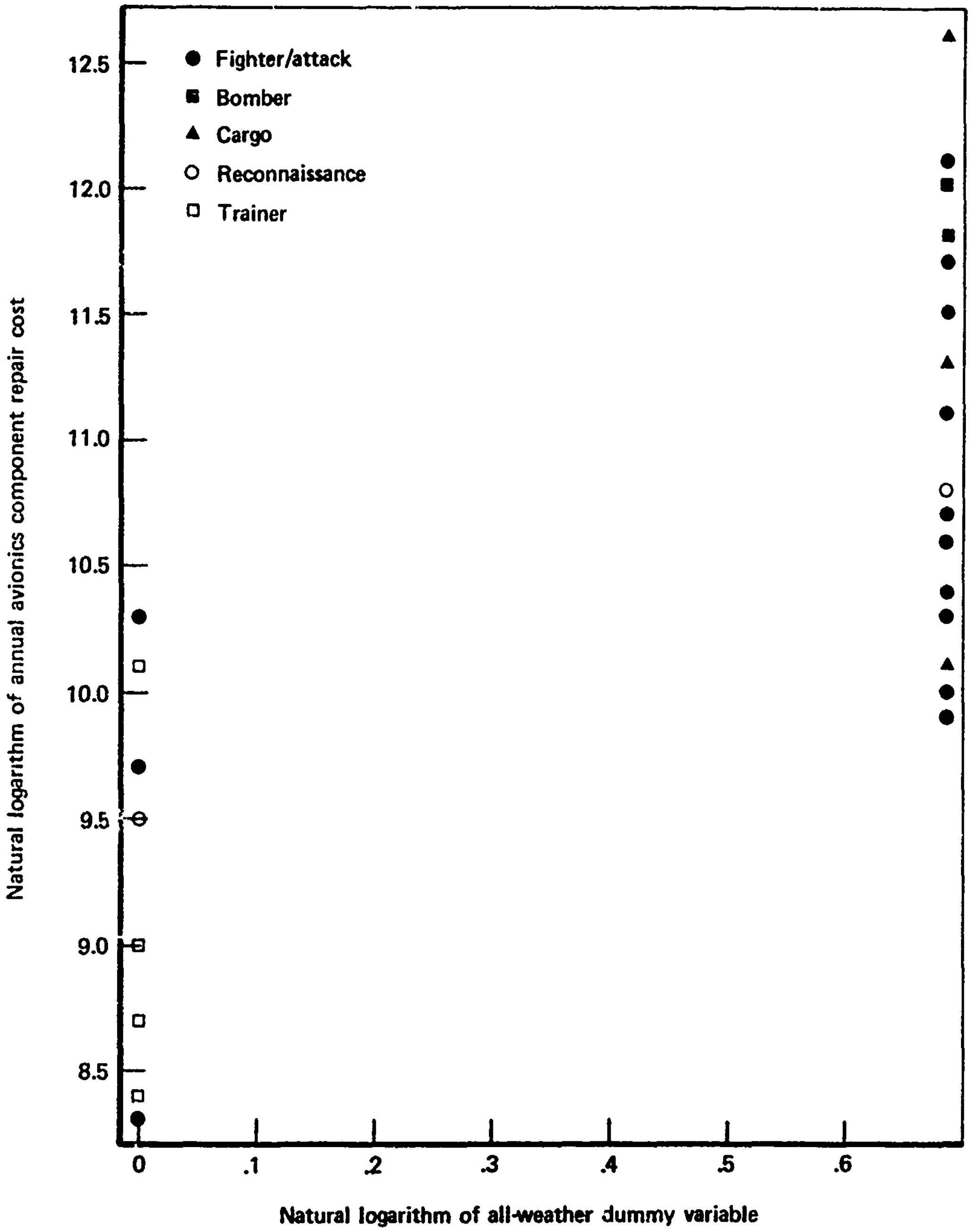

Fig. E.50—Variation of annual avionics component repair cost with all-weather dummy variable

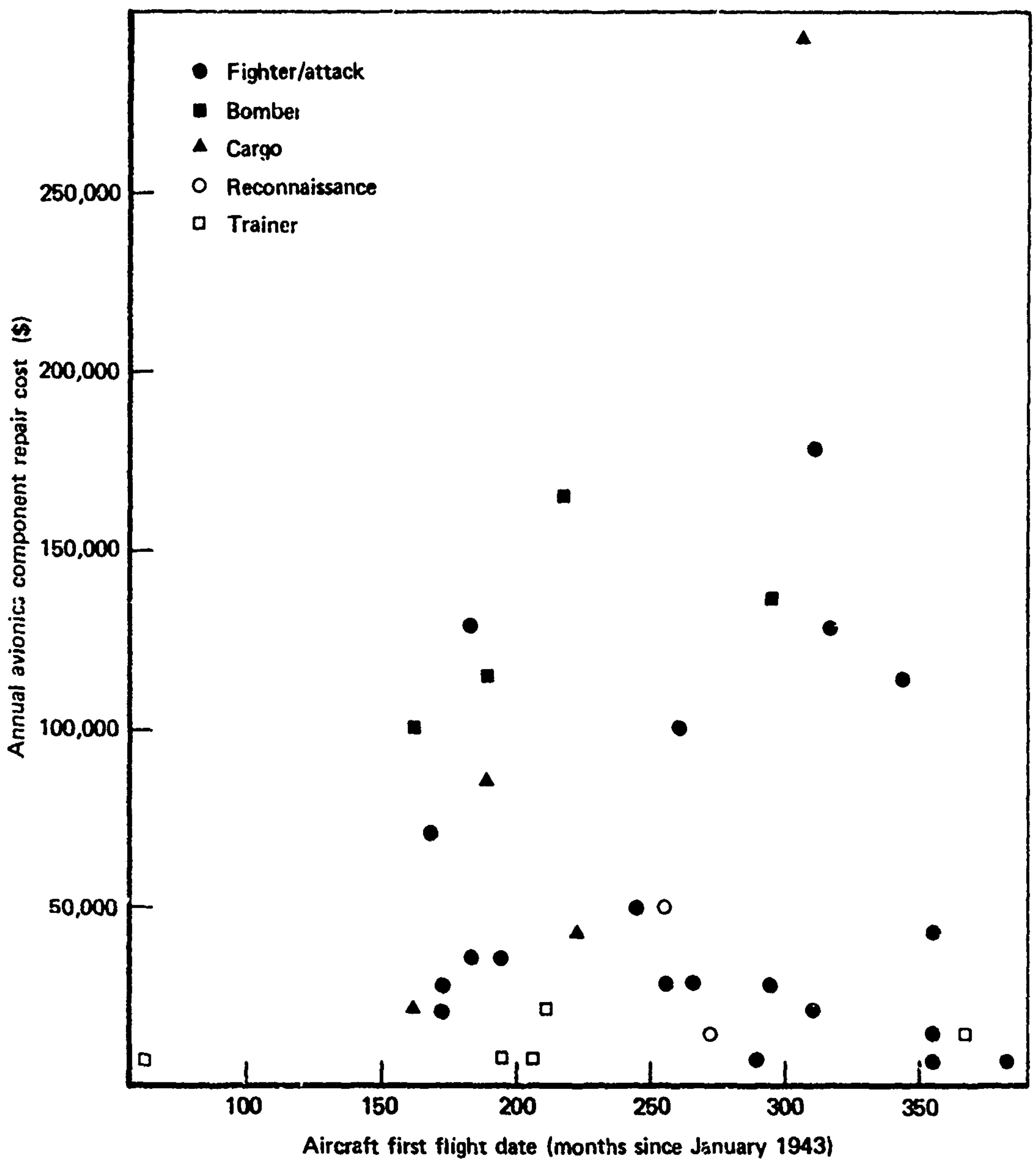

Fig. E.51—Variation of annual avionics component repair cost with aircraft first flight date

Appendix F

NOTE ON AIRFRAME REWORK COST

This appendix considers two alternative representations of airframe rework. In the first, the total annual cost for a fleet of aircraft is estimated directly. This method naturally has an inventory size or activity variable as a major explanatory variable; but with a large enough sample size, additional useful variables can be introduced into the equation. The particular nature of airframe rework makes this approach more appealing than it is for the other categories of maintenance activity. Airframe rework is a combination of PDMs and several other, less extensive, maintenance tasks, some of which take place during PDM visits. Airframe rework cannot be divided into two distinct activities (as can engine overhaul and engine repair). On the other hand, it is the result of a limited number of depot visits each year rather than a large number of small tasks (as is the case for component repairs). Estimating total cost also allows for the possibility of accounting for economies of scale.

The second alternative represents annual cost for a single weapon system as the product of (1) the average cost of a rework visit to the depot and (2) the average number of visits per year. For many systems, the prescribed interval between PDM visits was increasing during the years covered by our data. These increases are the result of management decisions based on knowledge gained during previous years of operation of the various weapon systems. The value of the prescribed interval may therefore be related to the age of the system. Since the actual average interval takes many months to transition from one prescribed value to another, there may be only a weak relationship between the production data in this study's data base and the intervals prescribed during the period covered by the data.

TOTAL ANNUAL FLEET COST

Based on the full sample of all types of aircraft, four variables were found to be related to total annual fleet cost: fleet flying hours (FH), empty weight (EW), production quantity (PQ), and PDM designation (PDM). According to these results, fleet rework cost is driven much more by aircraft size and utilization rate, and by policy decisions, than by technical characteristics. The variation of total cost with flying hours and empty weight is shown in Figs. F.1 and F.2. Other total cost plots are included in App. E. Tables F.1 and F.2 list the equations developed using these variables. The equations with the best statistics use combinations of two or three of the four variables. As much as 90 percent of the variance is accounted for by these equations. In these tables TOTCST is the total annual fleet airframe rework cost in 1978 dollars.

The exponent of the PDM policy variable in Table F.1 leads to a factor of 15 as the difference between the equation used for aircraft with a PDM program and for those without one. In other words, according to this result, not having a PDM program on a new aircraft would save about 93 percent of the airframe rework cost that would be incurred if a PDM were required. This equation, of course, says nothing about other costs that might be affected by such a decision. A PDM is only one part of a scheduled maintenance program. Avoiding use of a PDM could require larger than normal costs for base-level scheduled inspections. Also, unscheduled maintenance requirements could be larger than otherwise would be expected. Such effects are beyond the scope of this study but must be addressed in any application of the equations developed by the study.

A close examination of Fig. F.1 shows that, for high levels of flying activity, the total annual airframe rework cost data can be grouped into four classes. For a given flying-hour figure, the lowest rework cost is associated with trainers. The next class is made up of the light cargo aircraft: C-130E, C-141A, and KC-135. Even higher costs are associated with fighter/attack aircraft. The most costly aircraft, in terms of aircraft rework, are the heavy bomber and cargo aircraft:

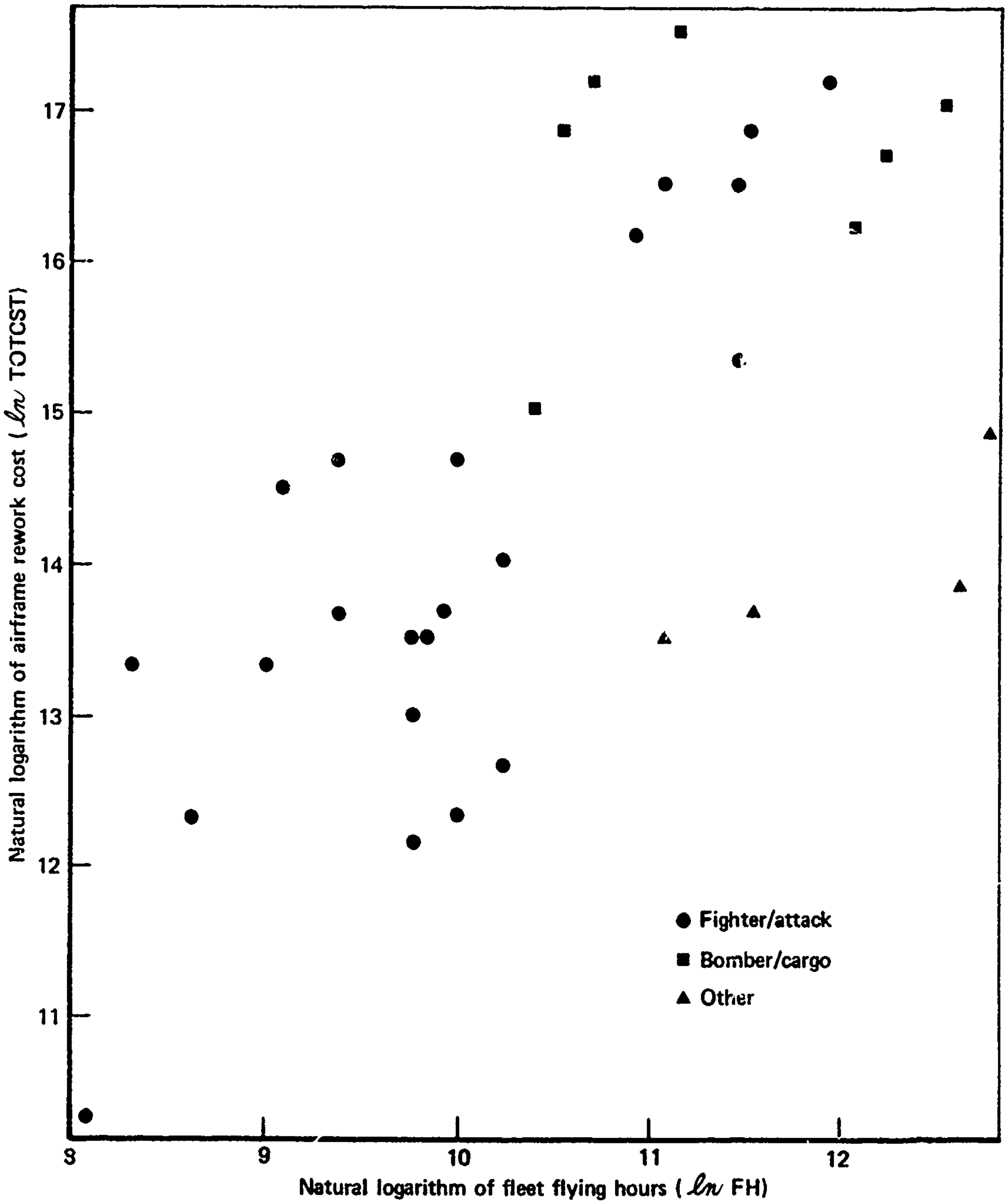

Fig. F.I—Variation of total airframe rework cost with fleet flying hours

Table F.1

TOTAL AIRFRAME REWORK COST EQUATIONS: FULL SAMPLE

Equation	Statistics			
	R^2	SEE	F	N
Size				
$TOTCST = 864.0\ EW^{0.8745}$ (.0009)	0.27	1.56	12	34
Utilization				
$TOTCST = 249.4\ FH^{0.9513}$ (.0000)	0.43	1.37	24	34
Policy				
$TOTCST = 388{,}100\ PQ^{0.7424}$ (.0000)	0.43	1.38	23	33
Size/Utilization				
$TOTCST = 0.0570\ FH^{0.9128}\ EW^{0.8154}$ (.0000) (.0000)	0.66	1.08	30	34
Size/Policy				
$TOTCST = 14.52\ EW^{0.9627}\ PQ^{0.7742}$ (.0000) (.0000)	0.71	0.99	38	33
Utilization/Policy				
$TOTCST = 2492\ FH^{0.5380}\ PDM^{3.899}$ (.0001) (.0000)	0.90	0.59	94	23
$TOTCST = 911.6\ FH^{0.6397}\ PQ^{0.4944}$ (.0013) (.0016)	0.58	1.21	21	33
Size/Utilization/Policy				
$TOTCST = 0.1152\ FH^{0.5688}\ EW^{0.8755}\ PQ^{0.5519}$ (.0000) (.0000) (.0000)	0.83	0.77	48	33

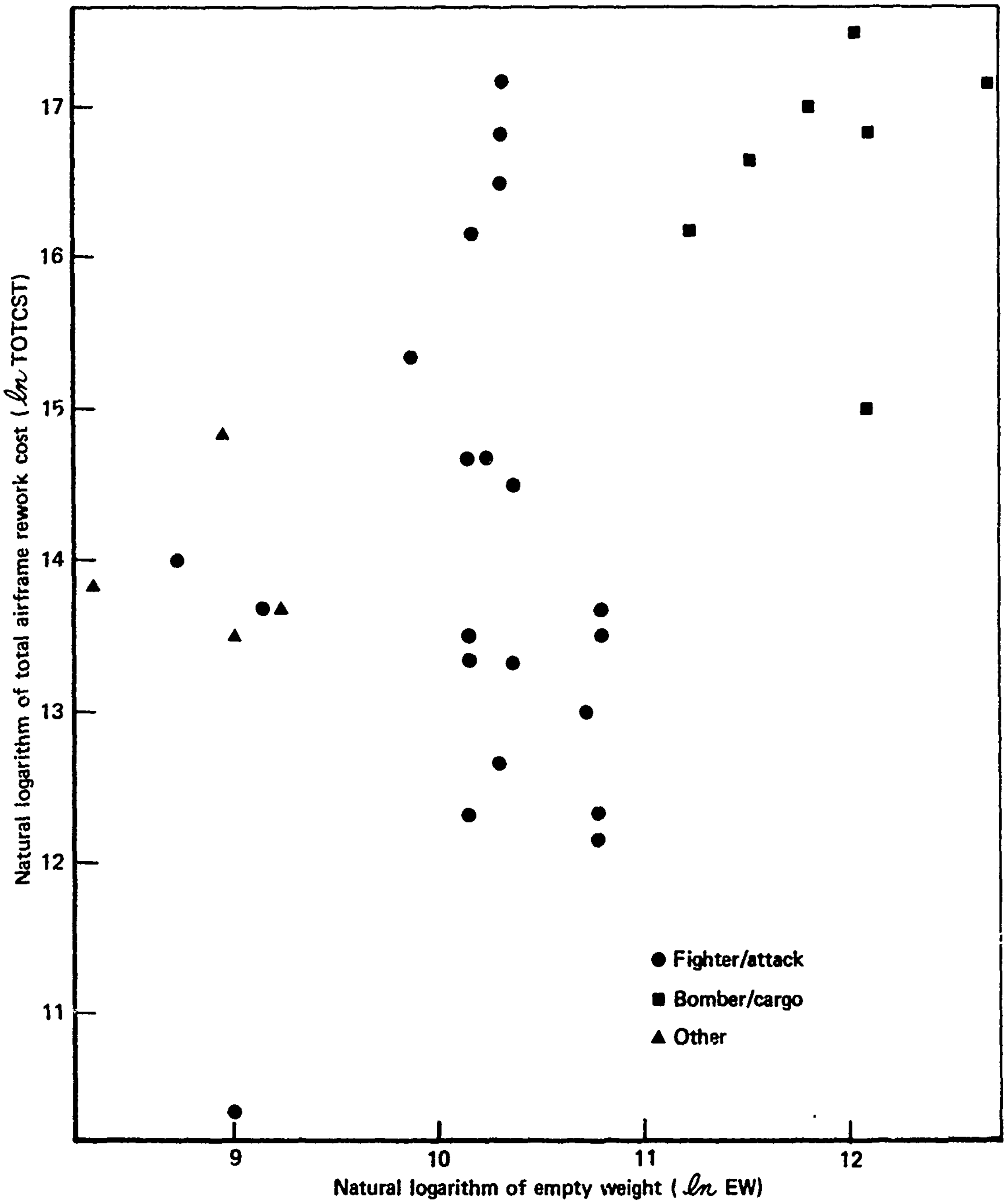

Fig. F.2—Variation of total airframe rework cost with empty weight

Table F.2

TOTAL AIRFRAME REWORK COST EQUATIONS: MOST REPRESENTATIVE SERIES

Equation	Statistics: R^2	SEE	F	N	Comments
Size					
$TOTCST = 368.8\ EW^{0.9514}$ (.0002)	.54	1.12	20	19	
Utilization					
$TOTCST = 2273\ FH^{0.7449}$ (.0161)	.24	1.44	5	19	
Size/Utilization					
$TOTCST = 0.2909\ FH^{0.6631}$ (.0019)	.73	.88	22	19	
Size/Policy					
$TOTCST = 56.15\ EW^{0.9079}\ PQ^{0.5191}$ (.0001) (.0051)	.69	.94	17	18	
Utilization/Policy					
$TOTCST = 2629\ FH^{0.5713}\ PQ^{0.4234}$ (.0474) (.0671)	.33	1.38	4	18	Fails F-test, PQ coefficient does not meet 5% significance criterion
Size/Utilization/Policy					
$TOTCST = 0.2063\ FH^{0.5408}\ EW^{0.8947}\ PQ^{0.4143}$ (.0037) (.0000) (.0062)	.82	.45	21	18	

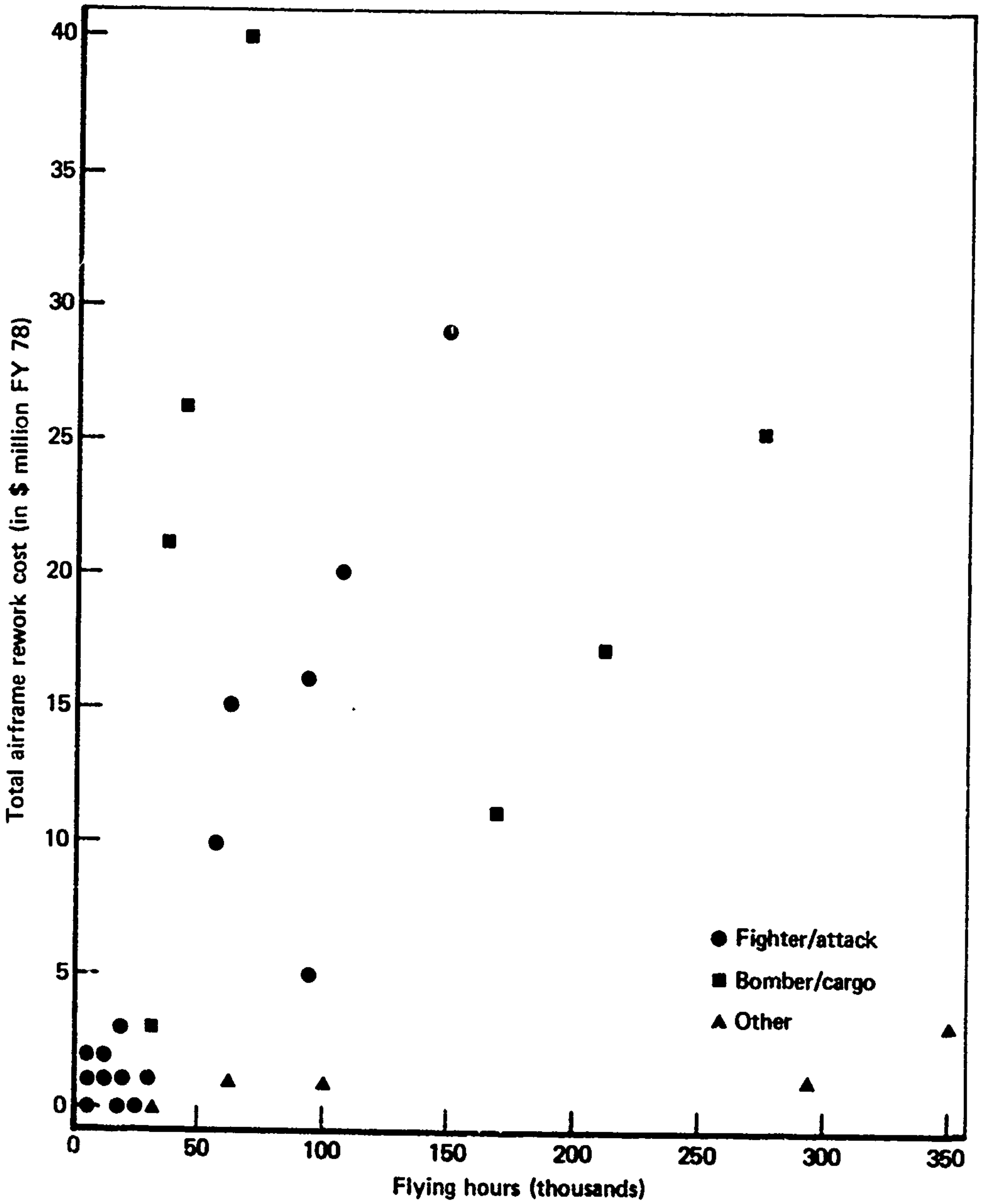

Fig. F.3—Total airframe rework cost for four classes of aircraft

Table F.3

TOTAL AIRFRAME REWORK COST EQUATIONS FOR FIGHTER/ATTACK AIRCRAFT

	Statistics				
Equation	R^2	SEE	F	N	Comments
Utilization					
$TOTCST = 4.354\ FH^{1.324}$ (.0000)	.69	.99	43	21	
Utilization-Technical/Performance					
$TOTCST = 0.003047\ FH^{1.289}\ MAXDLF^{3.735}$ (.0000) (.0250)	.74	.93	24	20	MAXLDF is not significant when used alone. Exponent magnitude.
Utilization/Policy					
$TOTCST = 35.22\ FH^{0.9574}\ PQ^{0.4020}$ (.0001) (.0023)	.80	.82	34	20	
$TOTCST = 78.37\ FH^{0.8971}\ PDM^{3.089}$ (.0017) (.0001)	.94	.47	76	12	
$TOTCST = 11{,}550\ INV^{0.8635}\ PDM^{3.356}$ (.0001) (.0002)	.95	.43	91	12	
Technical/Performance-Policy					
$TOTCST = 8.457\ MAXLDF^{5.636}\ PDM^{3.903}$ (.0010) (.0000)	.95	.44	86	12	MAXLDF is not significant when used alone. Exponent magnitude.

airframe production cost. These variables are highly correlated, and using them together generally produces an equation with unacceptable multicollinearity statistics. The best statistics are for equations that use all of these five variables except airframe cost.

Care should be used in applying the equations that include age as an explanatory variable. The age exponents are as large as 0.69, which would make a 20-year-old aircraft eight times as costly to maintain as a one-year-old aircraft. Examination of the data base reveals that the influence of age is derived largely from the F-15A and TF-15A, which

Table F.4

AIRFRAME REWORK-COST-PER-VISIT EQUATIONS: TOTAL SAMPLE

	Statistics			
Equation	R^2	SEE	F	N
Size				
$CSTPVST = 5.465\ \underset{(.0000)}{EW^{0.9462}}$	.48	1.04	29	33
Technical/Performance				
$CSTPVST = 136.0\ \underset{(.0003)}{AFMFGC^{1.047}}$	.41	.96	16	25
Utilization				
$CSTPVST = 43{,}010\ \underset{(.0039)}{AGE^{0.6084}}$	.22	1.24	8	31
Policy				
$CSTPVST = 9755\ \underset{(.0003)}{MAINTPCT^{0.6540}}$	.32	1.20	14	33
Size-Utilization				
$CSTPVST = 5.850\ \underset{(.0000)}{EW^{0.8465}}\ \underset{(.0024)}{AGE^{0.4589}}$	.64	.86	25	31
Size-Policy				
$CSTPVST = 6.871\ \underset{(.0001)}{EW^{0.7649}}\ \underset{(.0050)}{MAINTPCT^{0.4073}}$	.58	.95	21	33
$CSTPVST = 14.31\ \underset{(.0000)}{EW^{0.9281}}\ \underset{(.0250)}{PQ^{-0.2263}}$	.54	.99	18	33
Technical/Performance-Policy				
$CSTPVST = 88.43\ \underset{(.0015)}{MAINTPCT^{0.4930}}\ \underset{(.0010)}{AFMFGC^{0.8006}}$	.61	.80	17	25
Utilization-Policy				
$CSTPVST = 1196\ \underset{(.0001)}{MAINTPCT^{0.7792}}\ \underset{(.0002)}{AGE^{0.6944}}$	.53	.98	16	31
Size-Utilization-Policy				
$CSTPVST = 13.18\ \underset{(.0000)}{EW^{0.8306}}\ \underset{(.0011)}{AGE^{0.4738}}\ \underset{(.0184)}{PQ^{-0.2016}}$	.69	.81	20	31
$CSTPVST = 6.059\ \underset{(.0001)}{EW^{0.6471}}\ \underset{(.0053)}{MAINTPCT^{0.4488}}\ \underset{(.0003)}{AGE^{0.5\text{[illegible]}36}}$	.72	.78	23	31
$CSTPVST = 11\ 15\ \underset{(.0001)}{EW^{0.6652}}\ \underset{(.0002)}{AGE^{0.5421}}\ \underset{(.0134)}{MAINTPCT^{0.3809}}\ \underset{(.0471)}{PQ^{-0.1521}}$	.75	.75	19	31

Table F.5

AIRFRAME REWORK-COST-PER-VISIT EQUATIONS: MOST REPRESENTATIVE SERIES

Equation	R^2	SEE	F	N	Comments
	Statistics				
Size					
$CSTPVST = 9.542\ EW^{0.9009}$ (.0004)	.52	1.11	17	18	
Technical/Performance					
$CSTPVST = 248.3\ AFMFGC^{0.9736}$ (.0021)	.54	0.90	13	13	
Utilization					
$CSTPVST = 33{,}760\ AGE^{0.6096}$ (.0367)	.20	1.45	4	17	Not significant (fails F-test)
Policy					
$CSTPVST = 13{,}690\ MAINTPCT^{0.6361}$ (.0075)	.32	1.32	7	18	
Size-Utilization					
$CSTPVST = 4.222\ EW^{0.8656}\ AGE^{0.5430}$ (.0002) (.0094)	.69	0.94	16	17	
Size-Policy					
$CSTPVST = 12.81\ EW^{0.7374}\ MAINTPCT^{0.3732}$ (.0022) (.0398)	.61	1.03	12	18	
$CSTPVST = 55.15\ EW^{0.9097}\ PQ^{-0.4816}$ (.0001) (.0078)	.68	0.94	16	16	
Technical/Performance-Policy					
$CSTPVST = 145.9\ MAINTPCT^{0.3936}\ AFMFGC^{0.8190}$ (.0273) (.0037)	.69	0.78	11	13	
Utilization-Policy					
$CSTPVST = 916.7\ MAINTPCT^{0.8548}\ AGE^{0.7824}$ (.0007) (.0021)	.62	1.03	12	17	
Size-Utilization-Policy					
$CSTPVST = 4.692\ EW^{0.6235}\ MAINTPCT^{0.5393}\ AGE^{0.6706}$ (.0012) (.0044) (.0007)	.82	0.74	20	17	
$CSTPVST = 18.79\ EW^{0.8787}\ AGE^{0.4485}\ PQ^{-0.3732}$ (.0001) (.0144) (.0179)	.78	0.82	15	17	
$CSTPVST = 16.80\ EW^{0.6561}\ AGE^{0.5773}\ MAINTPCT^{0.4918}\ PQ^{-0.3242}$ (.0002) (.0007) (.0026) (.0094)	.89	0.61	24	17	

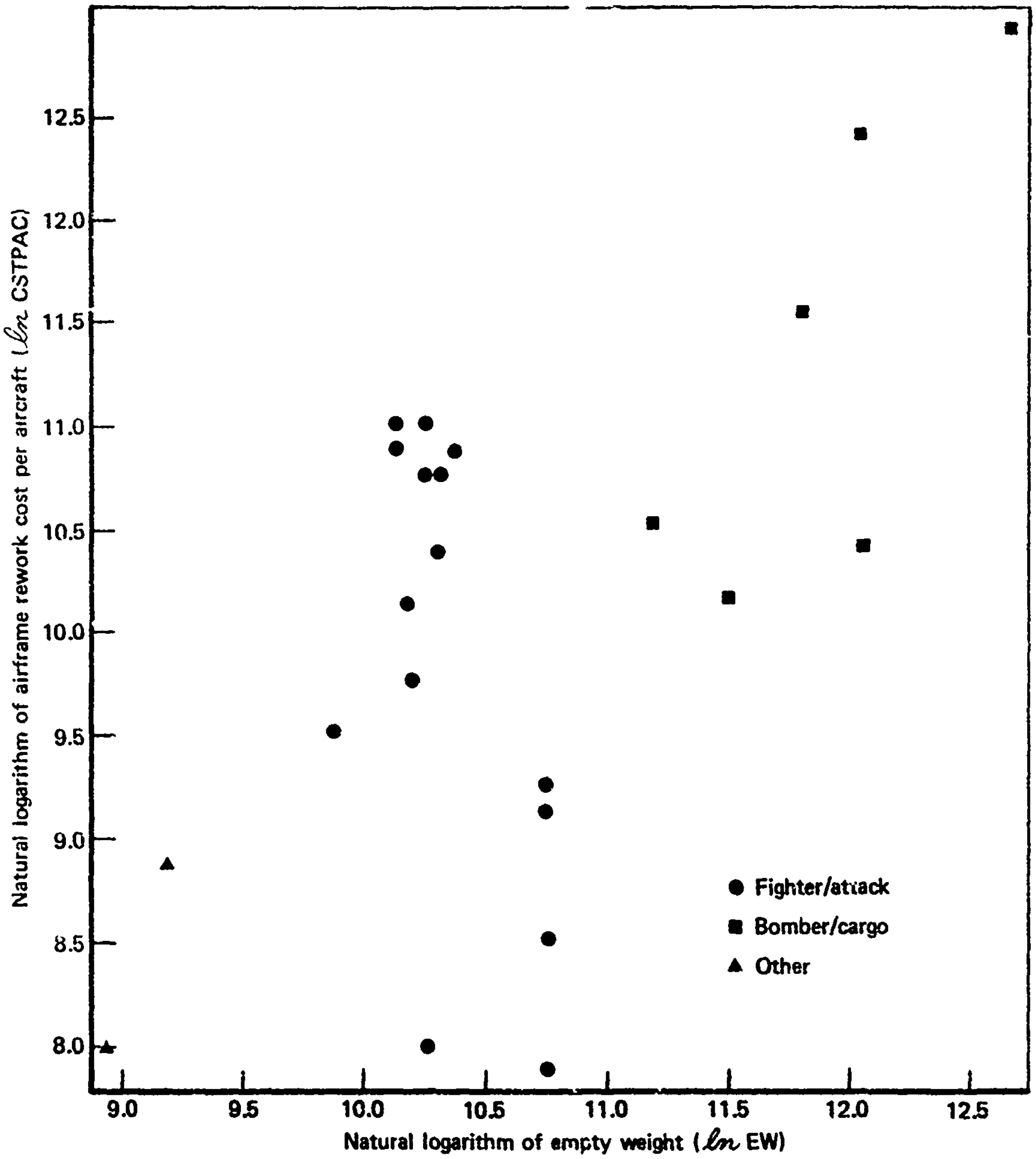

Fig. F.4—Variation of airframe rework cost per aircraft with empty weight

Table F.6

AIRFRAME REWORK-COST-PER-VISIT EQUATIONS FOR FIGHTER/ATTACK AIRCRAFT

Equation	Statistics R^2	SEE	F	N	Comments
Size					
$\text{CSTPVST} = 0.02166\ \underset{(.0010)}{\text{EW}^{1.480}}$	.40	1.02	13	21	
Utilization					
$\text{CSTPVST} = 28{,}930\ \underset{(.0022)}{\text{AGE}^{0.6325}}$	.39	0.99	11	19	
Policy					
$\text{CSTPVST} = 10{,}930\ \underset{(.0043)}{\text{MAINTPCT}^{0.5136}}$	.31	1.09	9	21	
Size-Utilization					
$\text{CSTPVST} = 0.3080\ \underset{(.0131)}{\text{AGE}^{0.4462}}\ \underset{(.0014)}{\text{EW}^{1.137}}$	.62	0.77	13	19	
Size-Policy					
$\text{CSTPVST} = 0.4302\ \underset{(.0148)}{\text{MAINTPCT}^{0.3645}}\ \underset{(.0070)}{\text{EW}^{1.039}}$	.53	0.89	10	21	
Utilization-Policy					
$\text{CSTPVST} = 2454\ \underset{(.0044)}{\text{MAINTPCT}^{0.5461}}\ \underset{(.0013)}{\text{AGE}^{0.6583}}$	.57	0.82	11	19	
$\text{CSTPVST} = 60{,}352\ \underset{(.0059)}{\text{AGE}^{0.6227}}\ \underset{(.0525)}{\text{PQ}^{-0.2182}}$	.44	0.97	6	18	PQ slightly exceeds the 5% significance criterion
$\text{CSTPVST} = 35.22\ \underset{(.0001)}{\text{FH}^{0.9574}}\ \underset{(.0001)}{\text{PQ}^{-0.5980}}$	.63	0.82	15	20	FH is not significant by itself
$\text{CSTPVST} = 79.24\ \underset{(.0015)}{\text{FH}^{0.7401}}\ \underset{(.0064)}{\text{AGE}^{0.4768}}\ \underset{(.0007)}{\text{PQ}^{-0.4654}}$	.69	0.73	11	19	FH is not significant by itself

Table F.7

AIRFRAME REWORK-COST-PER-VISIT EQUATIONS
FOR BOMBER/CARGO AIRCRAFT

Equation	Statistics			
	R^2	SEE	F	N
Size				
$CSTPVST = 0.009506\ EW^{1.453}$ $(.0159)$	.64	.58	9	7
Technical/Performance				
$CSTPVST = 4.633\ AFMFGC^{1.156}$ $(.0119)$	.67	.55	10	7

within the Air Force should visit the depot less often than one maintained under contract. Production quantity for the sample data is plotted versus inventory size in Fig. F.5.

In selecting an equation for use in estimating, one might first consider the problems associated with predicting the number of depot visits or production quantity. The results in Table F.8 fit the data rather poorly, so it might be best not to use them if an alternative can be found. If one has no other way of predicting the parameter, then it would perhaps be best to avcid the cost-per-visit equations and equations that use production quantity as an explanatory variable.

Table F.8

PRODUCTION QUANTITY EQUATIONS

Equation	Statistics R^2	SEE	F	N	Comments
Full Sample					
Utilization					
PQ = 28.38 + 0.3120 INV (<.0005)	.44	77	24	33	
PQ = 55.08 + .3542 INV − 3.983 AGE (<.0005) (<.15)	.52	75	15	31	AGE coefficient is not significant at 5% and is not significant when used alone
Utilization-Policy					
PQ = 82.70 + 0.2843 INV − 0.7184 MAINTPCT (<.0005) (<.05)	.50	74	15	33	
Sample of Representative Series					
Utilization					
PQ = 50.15 + 0.2479 INV (<.01)	.30	97	7	18	
PQ = 106.4 + 0.3023 INV − 7.641 AGE (<.025) (<.05)	.46	91	6	17	
Utilization-Policy					
PQ = 87.08 + 0.2383 INV − 0.6207 MAINTPCT (<.025) (<.20)	.35	97	4	18	MAINTPCT coefficient is not significant at 5% and is not significant when used alone

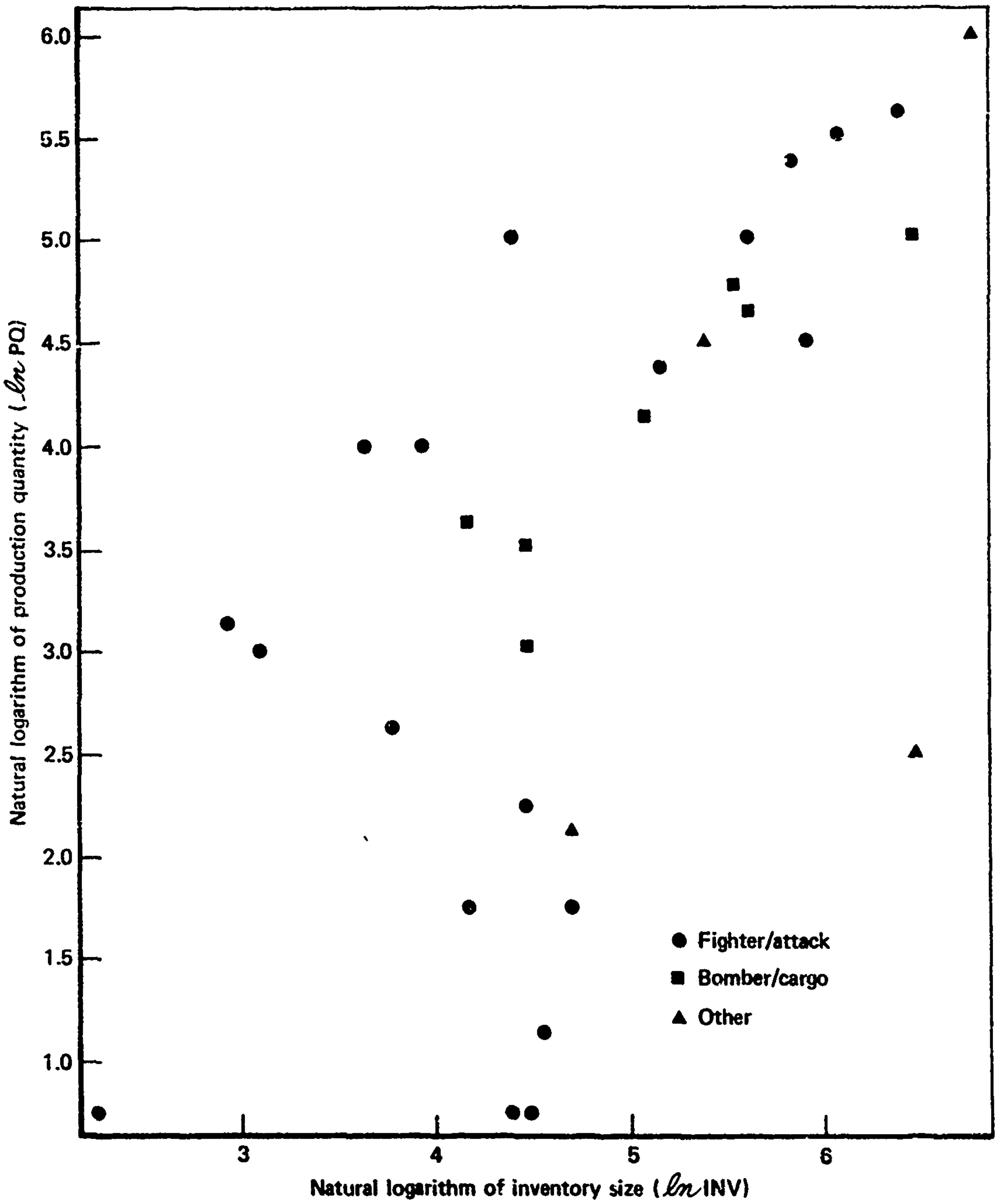

Fig. F.5—Production quantity reflects inventory size

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R-2731-PA&E Estimating Aircraft Depot Maintenance Costs, by Kenneth E. Marks, Ronald W. Hess. July 1981.

The following correction should be made on pp. xvii, 46, 65, and 100:

AFMFGC Airframe manufacturing cost; cumulative average cost of first 100 units, including manufacturing labor and materials (tens of thousands of FY 1978 dollars)

The following correction should be made to the heading appearing in Table D.1 on p. 123:

Airframe
Manufacturing
Cost
(78 \$ × 10^4)

Explanation: For equations using airframe manufacturing cost as an independent variable, cumulative total cost of the first 100 units, in millions of dollars, was inadvertently used in the statistical analysis. Thus, in order that the values of airframe manufacturing cost used in the statistical analysis correspond to the cumulative average definition used throughout the report, the units must be reduced from millions to tens of thousands.